ERDC/CERL TR-13-23

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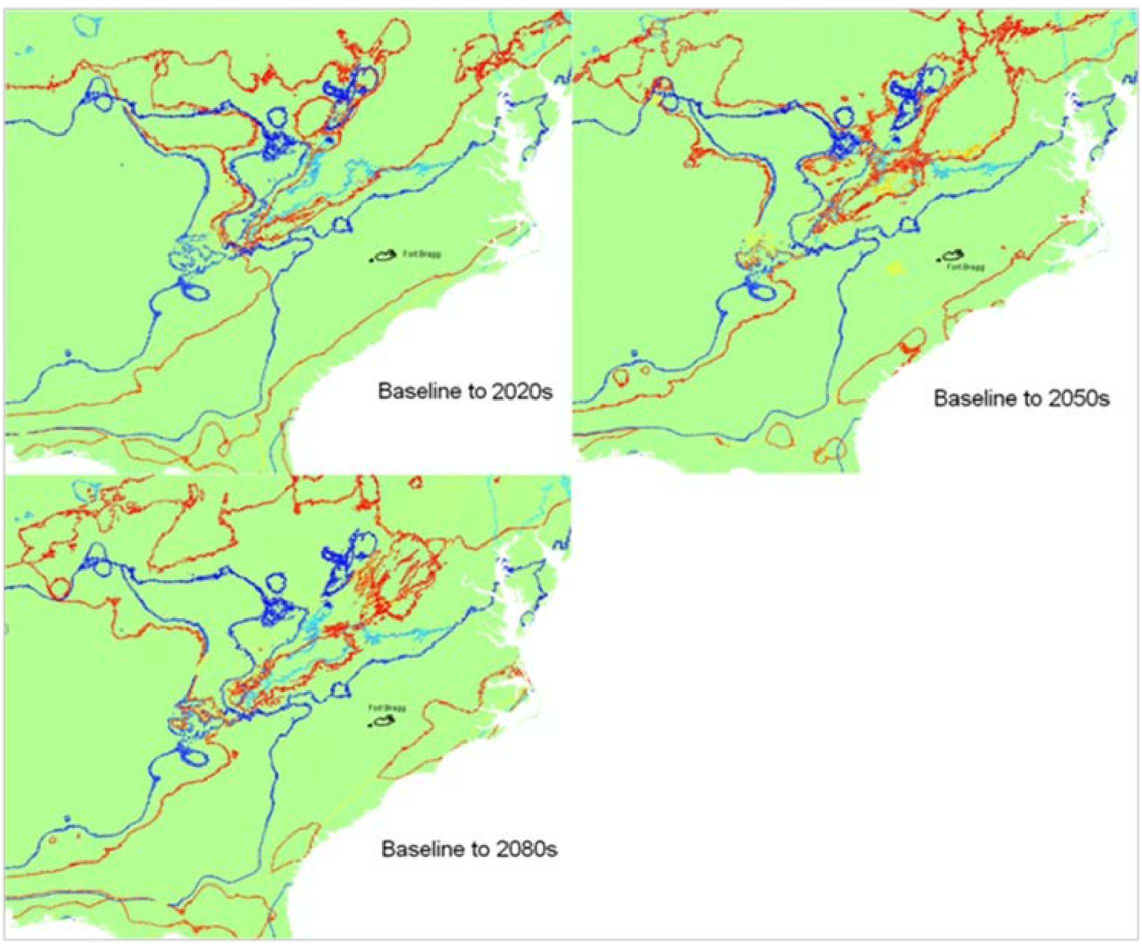
Anticipating Installation Natural Resource Climate Change Concerns

The Data

Robert C. Lozar, Matthew Hiett, and James D. Westervelt

October 2013



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Final Report

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Abstract

The effects of climate change are expected to impact military installations in the Continental United States (CONUS), including Army installations that have large land-based range areas used for testing, training, or maneuvers. Climate change has the potential to affect several management concerns at Army installations. Natural areas may shift on installations and change the costs to maintain training and testing areas. Climate change is likely to increase the management costs for Threatened and Endangered Species (TES) and noxious invasive species (NIS). This document describes a set of climate change data gathered to support a larger project undertaken to determine the thresholds of climatic characteristics of these targeted species. This work describes available climatic data that will show what the major Global Climatic Models (GCMs) predict about those changes, using Fort Bragg, NC as an example.

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Preface

This study was conducted for the Engineering Research and Development Center (ERDC) under the project, “Framework for Forecasting Climate Change Effects on Installation Natural Resources” as part of the “Prediction and Adaptation of Military Natural Infrastructure in Response to Climate Change” work package under the direction of Dr. Timothy Hayden, CEERD-CN-N. The technical monitor was Alan Anderson, CEERD-CV-T.

The work was performed by the Environmental Processes Branch (CN-N) of the Facilities Division (CF), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Dr Timothy Hayden. Gratitude is extended to Julian Ramirez-Villegas, a PhD and Research Assistant in Decision and Policy Analysis at the International Center for Tropical Agriculture (CIAT, Cali, Colombia) and Carlos Navarro, research assistant at CIAT, for all their work in helping to provide both data and subsequent support of that data. This report would not have been possible without their important contributions. William Meyer is Chief, CEERD-CN-N, and Dr. John Bandy is Chief, CEERD-CF. The Director of ERDC-CERL is Dr. Ilker R. Adiguzel.

CERL is an element of the US Army Engineer Research and Development Center (ERDC), US Army Corps of Engineers. The Commander and Executive Director of ERDC is COL Kevin J. Wilson, and the Director of ERDC is Dr. Jeffery P. Holland.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
cubic inches	0.00001638706	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	(5/9) x (°F – 32)	degrees Celsius
degrees Fahrenheit	(5/9) x (°F – 32) + 273.15	kelvins
feet	0.3048	meters
gallons (US liquid)	0.003785412	cubic meters
horsepower (550 ft-lb force per second)	745.6999	watts
inches	0.0254	meters
kips per square foot	47.88026	kilopascals
kips per square inch	6.894757	megapascals
miles (US statute)	1.609347	kilometers
pounds (force)	4.448222	newtons
pounds (force) per square inch	0.006894757	megapascals
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square meters
square miles	2,589,998	square meters
tons (force)	8,896.443	newtons
tons (2,000 pounds, mass)	907.1847	kilograms
yards	0.9144	meters

1 Introduction

1.1 Background

The 2007 *Fourth Assessment Report* by the Intergovernmental Panel on Climate Change (IPCC 2007a) states that, during the 20th century, global surface temperature increased 0.6 ± 0.2 °C (IPCC 2007b). Much of the observed temperature increase since the middle of the 20th century has been caused by increasing concentrations of greenhouse gases (GHGs), which result from human activities such as the burning of fossil fuel and deforestation. Global dimming, a result of increasing concentrations of atmospheric aerosols that block sunlight from reaching the Earth's surface, has partially countered the effects of warming induced by GHGs. Climate model projections (IPCC 2007b) indicate that global surface temperature is likely to rise between 1.1 and 6.4 °C during the 21st century.

The President's Council on Environmental Quality (CEQ) issued draft guidance (OSD 2010) to all Federal agencies concerning the manner in which climate change should be included in the evaluation of environmental effects under the National Environmental Policy Act (NEPA). Under NEPA, Federal agencies are required to evaluate the environmental impacts of proposed Federal actions and, wherever possible, to explore a broad range of options for minimizing potentially adverse outcomes and consequences that are caused – wholly or in part – by those actions. This new guidance extends the issues to be considered to include GHG emissions and climate change, and how agencies should address the interactions between their proposed actions and these factors. Specifically, the guidance states that:

> With regard to the effects of climate change on the design of a proposed action and alternatives, Federal agencies must ensure the scientific and professional integrity of their assessment of the ways in which climate change is affecting or could affect environmental effects of the proposed action ...
>
> Climate change can increase the vulnerability of a resource, ecosystem, or human community, causing a proposed action to result in consequences that

> are more damaging than prior experience with environmental impacts analysis might indicate ...
>
> Agencies should consider the specific effects of the proposed action (including the proposed action's effect on the vulnerability of affected ecosystems), the nexus of those effects with projected climate change effects on the same aspects of our environment, and the implications for the environment to adapt to the projected effects of climate change ...
>
> Where agencies consider climate change modeling to be applicable to their NEPA analysis, agencies should consider the uncertainties associated with long-term projections from global and regional climate change models ...

As with other agencies, the effects of climate change are expected to impact Continental United States (CONUS) military installations. In particular, Army installations have large land-based range areas used for testing, training, or maneuvers. Climate change has the potential to affect several management concerns at Army installations. Work in this area commonly aimed at the management of Threatened and Endangered Species (TES) and the potential appearance and increase of noxious invasive species (NIS).

1.2 Objective

The objective of this effort is to survey available Global Climatic Model (GCM) data and access the set of "best available data" intended to support the larger issue of determining the climatic thresholds for various plant and animal species.

1.3 Approach

Chapter 2 broadly reviews climate change research, with a focus on the predicted spatial distribution of expected changes.

Chapter 3 describes significant datasets and the procedures found in a survey of climate change data. GCM outputs of temperature and precipitation are the standard metrics likely to be of interest to TES and NIS researchers, both areas of considerable concern to Army installation land managers. Other researchers (Busby 1991, WorldClim 2012, CCAFS 2011) in the species and climatic characteristics fields have developed a set of useful derivative metrics that were found to be of great use in this project.

Chapter 4 describes in detail the characteristics of the best data found and extracted for this research, and provides a few simple illustrations of potential applications. Time horizons for these datasets were divided into four periods spanning from 1990 (the base year) to 2085, and that data used in illustrative applications is specifically for Fort Bragg, NC.

1.4 Scope

This investigation reviews the available literature that specifically supports the spatial distribution of climatic change predictions. This work made no attempt to generate new predictions.

1.5 Mode of technology transfer

This report will be made accessible through the World Wide Web (WWW) at URLs:

http://www.cecer.army.mil

http://libweb.erdc.usace.army.mil

2 Climate Change Modeling Review

2.1 General background to climate modeling

Research in the discipline of climate change dates back to the 1960s. the work of many individuals and groups to objectively understand the direction of climate change has generated many computer-based models. Some of the best known groups include National Center for Atmospheric Research (NCAR, in Boulder, CO), the Geophysical Fluid Dynamics Laboratory (GFDL, in Princeton, NJ), the Hadley Centre for Climate Prediction and Research (in Exeter, UK), the Max Planck Institute for Meteorology (in Hamburg, Germany), and the Institut Pierre-Simon Laplace (IPSL, in Paris, France).

All the respected models generate predictions based on a set of conventions disseminated through the IPCC. Such standardization is meant to facilitate comparison between models. As the predictive capabilities of climatic models are refined, discrepancies between them grow less significant. However, enough variation still exists that critics can use differences between the models to exaggerate the differences within climatic research. To minimize such confusion, the IPCC acts as a coordinating organization and its reports are intended to reflect the scientific consensus of the experts in the field.

2.2 Scenarios upon which climate modeling efforts are based

One of the primary responsibilities of the IPCC is the arrangement of a series of standard future scenarios to assist with coordination and comparison between model inputs and their results. This international standard set of scenario types is named after *The Special Report on Emissions Scenarios* (SRES). The SRES was prepared by the IPCC for the Third Assessment Report (TAR) in 2001 on future emission scenarios to be used to drive GCMs to develop climate change scenarios. The SRES were also used for the Fourth Assessment Report (AR4) in 2007. Table 1 lists the four scenario families.

Table 1. The four *SRES* scenario families of the *Fourth Assessment Report* with associated projected global average surface temperature increase by 2099.

Homogenous: Global*	A1 Rapid economic growth (includes groups: A1T; A1B; A1FI) **+1.4 – 6.4 °C**	B1 Global environmental sustainability **+1.1 – 2.9 °C**
Heterogeneous: Regional / Local	A2 Regionally oriented economic growth **+2.0 – 5.4 °C**	B2 Local environmental sustainability **+1.4 – 3.8 °C**
*Table format drawn partially from IPCC (2011).		

To put these scenarios in a slightly different light:

A1: Maximum energy requirements — emissions differentiated dependent on fuel sources

A1Fl: Fossil intensive

A1T: Technology development of non-fossil sources

A1B: Balance across sources

B1: Minimum energy requirements and emissions

A2: High energy requirements — emissions less than A1Fl

B2: Lower energy requirements — emissions greater than B1.

2.3 The major climate models

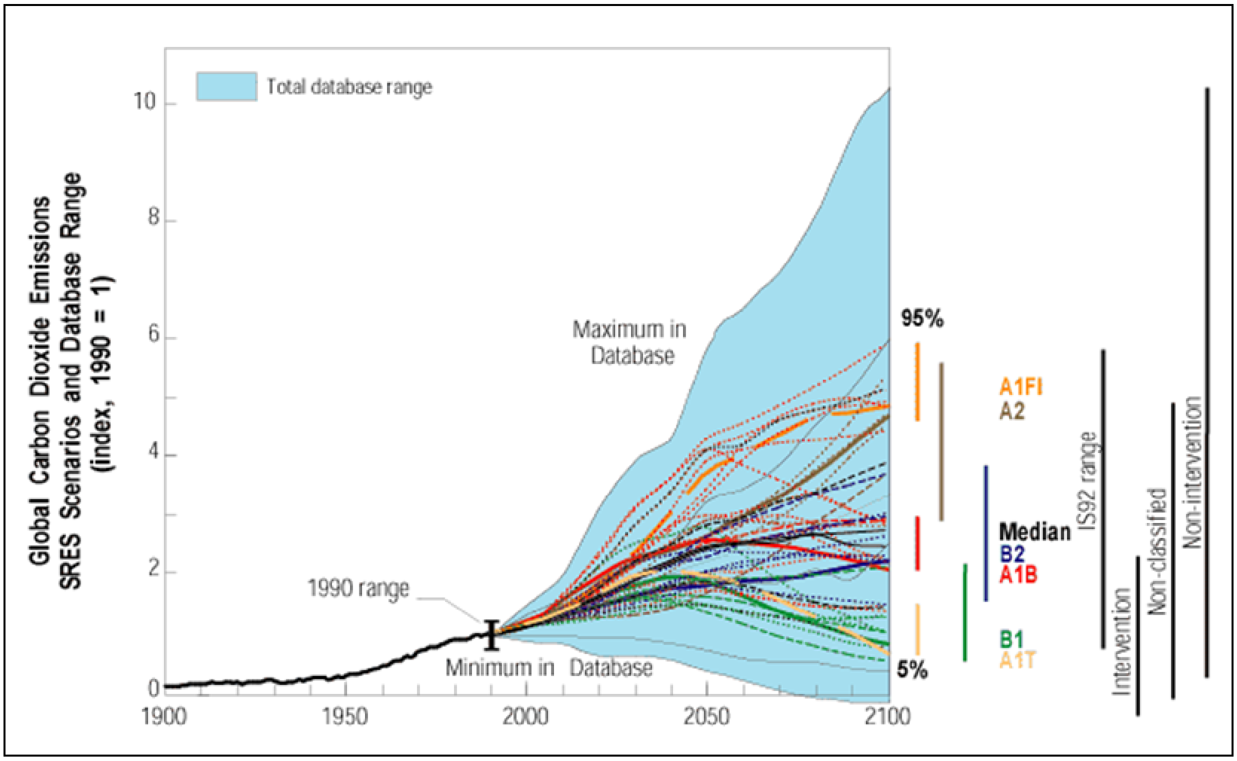
Since the 1990s, the international climate change science community has participated in a series of efforts (often called "campaigns") to carry out major, mostly coordinated attempts to exercise their best available modeling capabilities under similar sets of SRES scenarios. This study used the most recent model results, i.e., the AR4 (IPCC 2009). Table 2 lists the major participants in the AR4 campaign and the name of their most recent models. The next major coordinated modeling effort will be the IPCC Fifth Assessment Report (AR5), which will be finalized in 2014. Modeling efforts for AR5 have already begun.

Figure 1 shows different model and scenario results and how they diverge over time. Near-term results can be considered more creditable than those that approach 2099.

Table 2. SRES scenario runs for AR4 (August 2006 data).

	Country	Acronym	Model Name
Beijing Climate Center	China	BCC	CM1
Bjerknes Centre for Climate Research	Norway	BCCR	BCM2.0
Canadian Center for Climate Modelling and Analysis	Canada	CCCma	CGCM3 (T47 resolution) CGCM3 (T63 resolution)
Centre National de Recherches Meteorologiques	France	CNRM	CM3
Australia's Commonwealth Scientific and Industrial Research Organization	Australia	CSIRO	Mk3.0
Max-Planck-Institut for Meteorology	Germany	MPI-M	ECHAM5-OM
Meteorological Institute, University of Bonn	Germany	MIUB	ECHO-G
Meteorological Research Institute of KMA	Korea	METRI	
Model and Data Groupe at MPI-M	Germany	M&D	
Institute of Atmospheric Physics	China	LASG	FGOALS-g1.0
Geophysical Fluid Dynamics Laboratory	USA	GFDL	CM2.0 CM2.1
Goddard Institute for Space Studies	USA	GISS	AOM E-H E-R
Institute for Numerical Mathematics	Russia	INM	CM3.0
Institut Pierre-Simon Laplace	France	IPSL	CM4
National Institute for Environmental Studies	Japan	NIES	MIROC3.2 hires MIROC3.2 medres
Meteorological Research Institute	Japan	MRI	CGCM2.3.2
National Centre for Atmospheric Research	USA	NCAR	PCM CCSM3
UK Met Office (Hadley Centre)	UK	UKMO	HadCM3 HadGEM1
National Institute of Geophysics and Volcanology	Italy	INGV	SXG 2005
*AR4 table from IPCC (2010).			

Figure 1. Variation between GCMs showing ranges within scenarios.



2.4 Which predictive models to choose for this work?

To determine the "best" of all the available models for future predictions of different variables, one objective criterion to consider is, which models have demonstrated the closest validation with the variables of interest — for example, precipitation over CONUS. Those models that have had the greatest number of validation studies and those with the longest-period of development (1 to 2 decades) include:

1. $CM_{2.1}$ (GFDL model — NOAA Princeton)
2. E-H and E-R (NASA GISS)
3. $HadGEM_1$ (Hadley UKMO)
4. $CGCM_3$ (Canadian (CCCma) model)
5. $CCSM_3$ (NCAR Boulder).

To their credit, these top models have the longest history and largest number of peer reviewed publications. Thus, this research attempted to include as many of these models as possible, and to exclude models with shorter lifetimes of development, and fewer person-hours involved in their validation and calibration.

2.5 Problems with the output of the climate models and the desired solution

The characteristics of basic climatic models presented several major problems due to. First, temperature and precipitation (and possibly humidity) are the major outputs that would be useful for the characterization of species changes. Although other outputs are available, they do not relate well to issues that have an effect on the life habits of different species. Fortunately, other studies (WorldClim 2012, CCAFS 2011) have established that it is possible to extract data that are highly important to species viability from this simple temperature and precipitation output. Chapter 3 deals with this in detail.

The second issue is more problematic. GCMs geographically referenced data are gross in size. In fact, most GCMs output their results in a grid format that is roughly 3 x 3 degrees (~330 km at 30 degrees north) in size (see Figure 2). It became apparent that using such generalized data would result in less than satisfactory results. Fortunately others in the field have agreed that this was an issue (Climate Central et al. 2012, CCAFS 2011) and have carried out "downscaling" on the GCM data. "Downscaling," or refining the climate model results to specific regions involves a focus on more local concerns such as topography, surface winds, evaporation, and local precipitation. This is done through the application of dynamic and statistical processes. Statistical downscaling is useful for adjusting GCM scenarios to the local climate observations when and where local observations are available (Climate Central et al. 2012). Future climate scenarios has been downscaled to a resolution of 1/8 degree (about 13 km, see Figure 3) using statistical approaches, mostly for average temperatures and precipitation.

Another problem was the nature of the GCM data. At the project's outset, the intention was to begin with downscaled data acquired for a previous effort (Lozar 2011). Figure 4 shows a range of temperature predictions for Fort Bragg, plotted from the previously compiled data. There appear to be wide temperature swings among the models and even within a single model in the first few decades of the 21st century. Later (2050-2099), the variability seems to decrease, but this could easily be the result of fewer data points. Both the A2 (red) and B1 (green) scenarios seem to overlap a great deal, such that no pattern appears evident.

Figure 2. The coverage of a single temperature data point from Canadian CGCM3 model (shown in green).

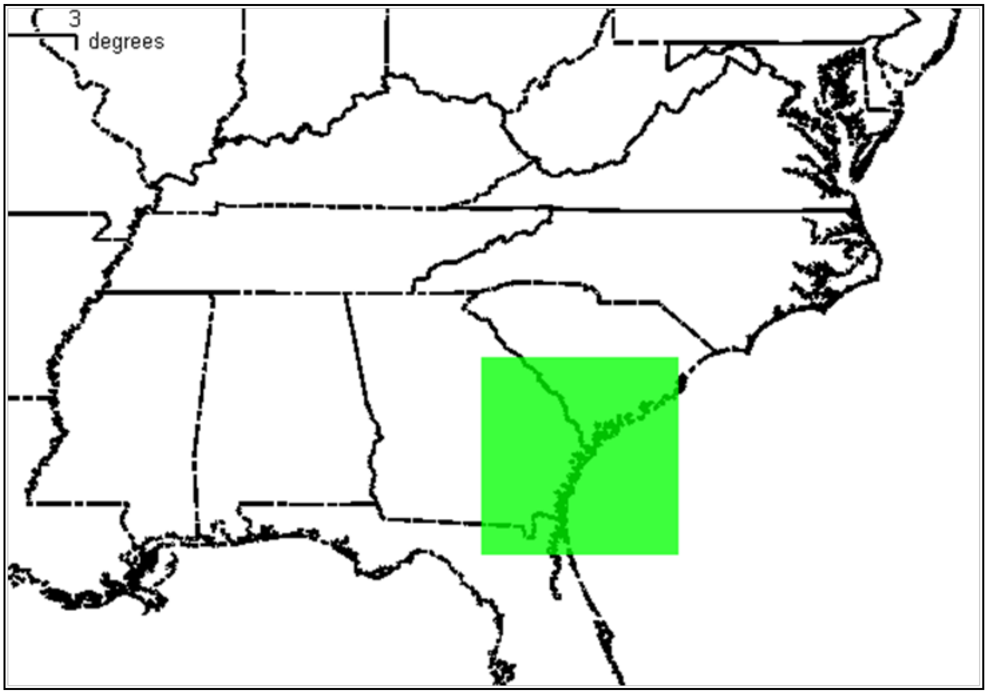


Figure 3. The square around Fort Bragg is 3 degrees on edge- one GCM pixel; much greater detail is made available by downscaling on the same model for the year 2000 for monthly precipitation.

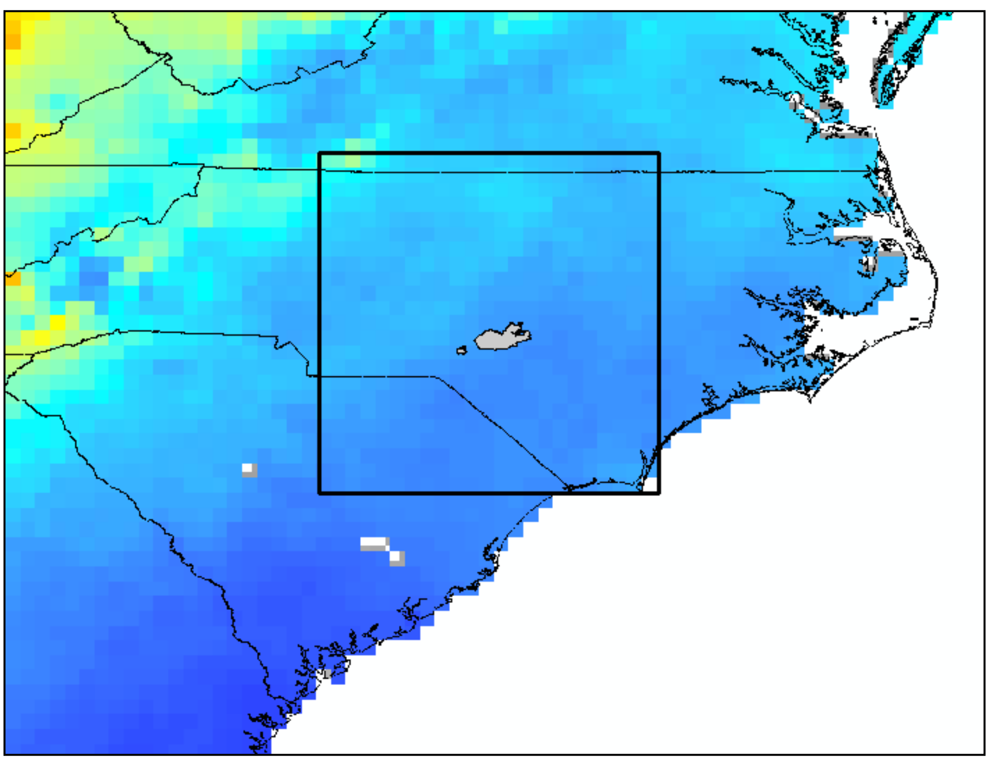
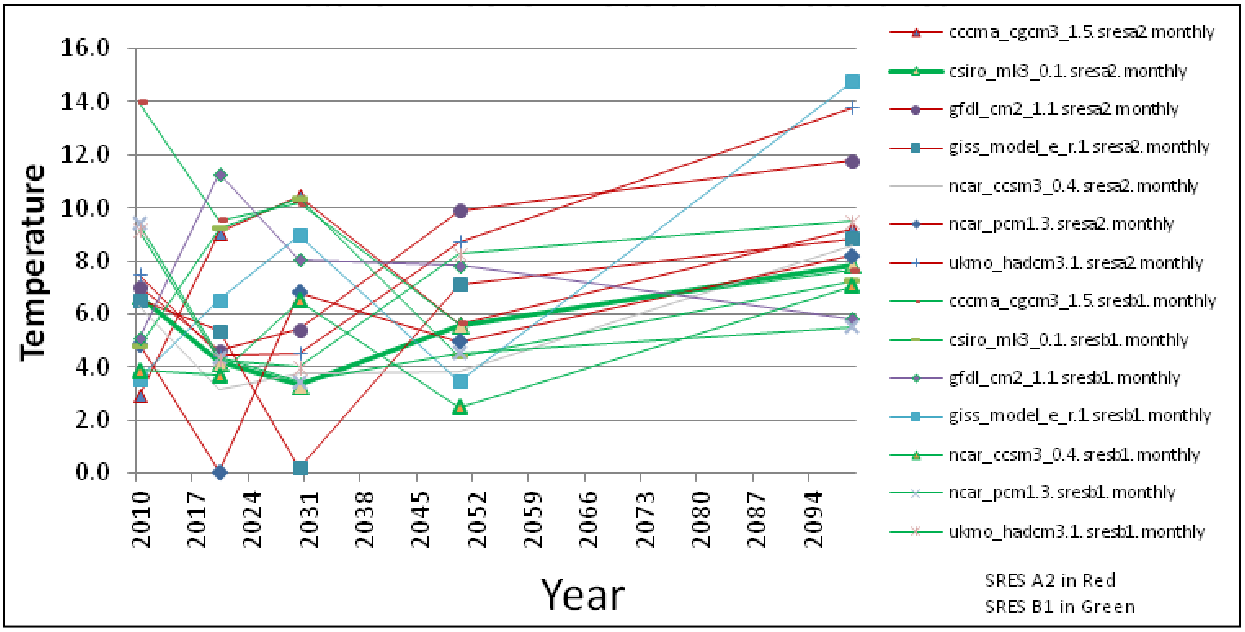


Figure 4. Fort Bragg predicted temperature changes for seven models and two scenarios.



After reviewing this variable GCM data, it became apparent that it would be difficult to justify sensible trends based on data that varied so widely within itself. Discussions with John W. Weatherly (ERDC-CRREL) clarified that the reason behind the variation was that the data were weather predictions rather than climate predictions, i.e., GCMs are designed to mimic weather patterns with built-in random variation. The implication of this randomness became almost immediately apparent.

To extract the climatic information required for this project would require averaging the data over a 20- to 30–year time horizon, using the midpoint date as the climatic data point. Such an effort would require a great deal more data than was then available, plus large amounts of computer calculations to generate the desired midpoint data. This would require the use of several years of data on either temporal side of the target year, which would be averaged to develop a climatic representation.

Unfortunately, such averaging removes the extreme minimums and maximums that have the greatest effect on plant and animal communities. For non-averaged data, it would be possible to use the downscaled data from Figure 4 that previously contained too much randomness. However, extreme weather events in the downscaled data are not predictive. It would be possible to say that a particular maximum temperature would be N °C and that in 100 years it would occur with Y frequency, but it would not be possible to say accurately when those critical events might occur. This seems to be an acceptable tradeoff for those who model thresholds, but it also implies it would be necessary to download all 100 years of downscaled data instead of simply using data from a few snapshot years. Fortunately, others (WorldClim 2012, CCAFS 2011) have carried out the required data manipulation to generate predictive climatic data needed for this work.

Therefore, the ideal result of this effort would be to find high-resolution downscaled data that:

- represents more than just temperature and precipitation
- has been averaged over a multiple decades to create climatic data
- would provide projections in the relatively near term (~2025s)
- include at least five established GCMs for a large set of the IPCC scenarios.

3 In Search of the Ideal Dataset

3.1 Preliminary research

The revision of the basic dataset was begun by:

- downloading all the data available from our original source
- reformatting it to a standard GIS form
- averaging it over decades
- generating results similar to those shown in Figure 4, but smoothed.

At the beginning of this process, the research team also began to investigate data already available through the Internet, particularly that available via WorldClim.* Climate Change Agriculture and Food Security (CCAFS 2011) uses the WorldClim source to generate 19 corollary biologically related datasets, and these additional datasets:

- consecutive months – the maximum number of consecutive dry months (<100 mm) in a year
- precipitation by month
- temperature maximum by month
- temperature mean by month
- temperature minimum by month.

This work used the WorldClim dataset, which represents downscaled data from weather stations over a period of 1950-2000,† to represent "current" conditions.

3.2 CIAT data

The International Centre for Tropical Agriculture (CIAT) has downscaled future climate projections from the IPCC, and has also made available sets of 19 bioclimatic concerns ("bioclim" data) useful in characterizing the biological environment and the predicted GCM changes.‡

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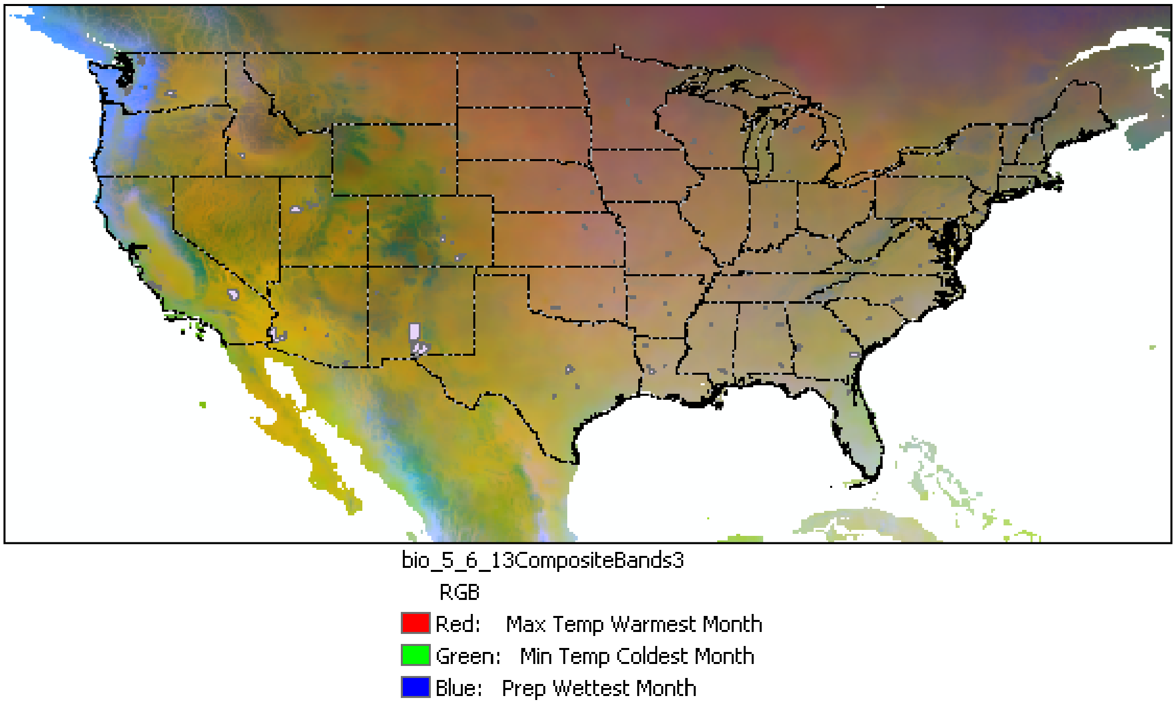
* http://www.worldclim.org/

† Available via http://www.worldclim.org/current

‡ http://ccafs-climate.org/download_down.html

Figure 5. CIAT bioclimatic data content illustration. Where Red predominates the warmest month is significantly warm. Where green predominates, the coldest month is very cold. Where Blue predominates, the wettest month is most important (e.g., the rainforests of the Pacific Northwest). Similarly darker colors suggest the area is lower in all three concerns (Canada) than brighter locations (Arizona).



These are comparable at 30 arc-seconds (~1 km) resolution to the WorldClim data and include both the baseline and bioclimatic data layers. Since this work is interested in the ecological situation at a specific military installation, these 19 parameters represent many of the concerns that would have a stressing effect on the flora and fauna in a locality. They are derived directly from the base temperature and precipitation data using ArcGIS and an open source GIS program, DIVA-GIS (Hijmans 2012). The CIAT web site clearly documents characteristics of the data. The following paragraphs describe how well the data fulfills the stated criteria for "ideal" high-resolution downscaled data.

3.2.1 High-resolution downscaled data

Although CIAT provides several different resolution datasets, the ~1-km^2 dataset (their highest resolution) was selected. These data are downscaled to a similar resolution as the dataset the research team had used previously so the data provide some variation over large installations and within the immediate regions of any Army installation.

3.2.2 Averaged over a few decades to get climatic data

The CIAT “Delta method” data are averaged over 30 years of GCM data with the average centered with 15 years of data on either side of that date. So, the data meant to represent the “2025s” is an average of GCM output from 2010-2039. Also, the WorldClim site provided historical data that have been averaged over the course of 50 years between 1950 and 2000.

3.2.3 For the five best respected GCMs for a large set of the IPCC scenarios.

CIAT has done their processing on many GCMs, including the entire five target GCMs of most interest to this project. In addition, researchers requested a sixth GCM, the Australian CSIRO model, to increase the sample. Thus the adopted GCMs include:

1. GFDL model (NOAA Princeton)
6. GISS Model e (NASA GISS)
7. UKMO (UK Hadley Center)
8. CCCMA (Canadian model)
9. CCSM3 (NCAR Boulder)
10. CSIRO (Australia).

Note that three scenarios were downloaded for each GCM: A1B, A2, and B1.

3.2.4 From which could be extracted some reasonably near-term data

With the baseline data from the 20th century, the time horizon and intervals for the data used are:

- late 20th century, or “current”
- 2010-2039 (henceforth called 2025s)
- 2040-2069 (henceforth called 2055s)
- 2070-2099 (henceforth called 2085s).

Thus the 2025s data represent a time frame of just over 12 years from now, within a reasonable planning horizon for installations.

3.2.5 Represented bioclimatic variables

In addition to the basic database, WorldClim also provides 19 “bioclimatic” variables that have been derived from the three basic climatic variables (minimum/maximum temperature and precipitation), and that are found in the downscaled GCM data. CIAT has calculated the same bioclimatic layers for its downscaled future projections, and has provided documentation for deriving the bioclimatic variables from any basic climate change data (Ramirez and Bueno-Cabrera 2009). The types they generated are parallel with those the others have set as a "Bioclimatic Industry Standard" (Phillips, Anderson, and Schapire 2006).

The variables included in the CIAT and WorldClim bioclimatic data (Hijmans, Cameron, and Parra 2012; CCAFS 2011a) are:

- Derived from maximum and minimum temperature:
  - BIO1 = Annual Mean Temperature (°C times 10)
  - BIO2 = Mean Diurnal Range (Mean of monthly (max temp -min temp))
  - BIO3 = Isothermality (mean diurnal range/temperature annual range)
  - BIO4 = Temperature Seasonality (standard deviation *100) (°C times 10)
  - BIO5 = Max Temperature of Warmest Month
  - BIO6 = Min Temperature of Coldest Month
  - BIO7 = Temperature Annual Range (Bio5-Bio6)
  - BIO8 = Mean Temperature of Wettest Quarter
  - BIO9 = Mean Temperature of Driest Quarter
  - BIO10 = Mean Temperature of Warmest Quarter
  - BIO11 = Mean Temperature of Coldest Quarter
- Derived from precipitation:
  - BIO12 = Annual Precipitation (in millimeters)
  - BIO13 = Precipitation of Wettest Month
  - BIO14 = Precipitation of Driest Month
  - BIO15 = Precipitation Seasonality (Coefficient of Variation)
  - BIO16 = Precipitation of Wettest Quarter
  - BIO17 = Precipitation of Driest Quarter
  - BIO18 = Precipitation of Warmest Quarter
  - BIO19 = Precipitation of Coldest Quarter
  - cons_mths = Consecutive Months – the maximum number of consecutive dry months (<100 mm) in a year.

3.3 Limitations of the CIAT data

The CIAT data reflect the standard bioclimatic datasets being generated. Still, it remains to be determined—how well the CIAT data fulfills the needs of this project, i.e., the management of TES and the potential appearance and increase of NIS.

3.3.1 Climate vs. weather data

A primary issue in TES and NIS management involves changes in climatic parameters that pass a critical threshold, beyond which there is a significant difference in a species' viability to survive. It is not within the scope of this project to determine the thresholds for particular species; rather, the objective of this work is to identify the climatic data that supports the identification of those thresholds.

Consultation with staff working on related research (Hayden 2011) revealed that thresholds are likely to be found at the extremes of climatic data rather than at the norm (norm being climatic data, extremes to be found in daily weather type data). Recall that the problem with the data from a previous related project (Lozar 2011) had was that it mimicked weather data with a built-in random component; the search for averaged-over-time datasets was undertaken to overcome this problem. It may seem reasonable to question whether it is possible to use randomized GCM data for climate change issues, but this is emphatically not the case. Because GCM data are predictive, any occurrences of extreme values not only are fictitious, but random. At best, one could say that an extreme value occurs X times in the next 100 years. However, since the extreme is random, one could not locate that event in time. Therefore, it is not useful to know the frequency of occurrence that could, for example, occur in 2012 or 2085.

3.3.2 Forest vegetation simulator categories

Work done by the US Forest Service at the Moscow Forestry Sciences Laboratory (USDA 2012) created data that would be useful to the related threshold project. This US Forest Service date were similar to those of the CIAT bioclimatic derivations, but with different output datasets (created using the Forest Vegetation Simulator [FVS] modeling system). Unfortunately, the data include only three GCMs for the years 2030, 2060, and 2090 and only extend to a portion of the Western United States (and thus does not include Fort Bragg). Still, it is instructive to compare the two datasets to see how well the FVS (Table 3) compares with CIAT data in supporting TES/NIS threshold work. The primary issue for threshold work is that both datasets use averaged GCM data. Thus, neither deals with extreme occurrences. In this critical respect, they are similar.

Note that "degree-days" unit in Table 3 is used in estimating the demand for energy required for heating or cooling. In the United States, the typical standard indoor temperature is 65 °F. For each 1 °F decrease or increase from this standard in the average outside temperature, 1 heating or cooling degree day is recorded. For example, an average outside temperature for a day of 60 °F, records as 5 heating degree-days (HDD); if it were 70 °F, it would record as 5 cooling degree-days (CDD).

These concerns focus on issues relevant to questions of stress on vegetative communities. Since these data are available for only Western US locations at this time, data was requested for Fort Irwin, CA (Appendix A). Of the 18 variables listed, only 12 (highlighted in grey in Table 3) could be identified in the Fort Irwin output.

Table 3. The FVS set of concerns.

1	Mean annual temperature
2	Average temperature in the coldest month
3	Minimum temperature in the coldest month
4	Average temperature in the warmest month
5	Maximum temperature in the warmest month
6	Annual precipitation
7	Growing season precipitation: April – September
8	Summer-winter temperature differential (Variable 4 – Variable2)
9	Degree-days >5 °C
10	Degree-days <0 °C
11	Minimum temperature of degree-days <0 °C
12	Julian date of the last freezing date of spring
13	Julian date of the first freezing date of autumn
14	Length of the frost-free period
15	Accumulated degree-days >5 °C within the frost-free period
16	Julian date when the sum of degree-days >5 °C reaches 100
17	Annual dryness index: Ratio of Variable 9 to Variable 6
18	Summer dryness index: Ratio of Variable 15 to Variable 7

3.3.3 FVS data categories compared to the CIAT categories

A side-by-side comparison of FVS and CIAT categories of resolves the question of which of the desired FVS data types can be obtained from the CIAT bioclimatic data, and which sets are directly comparable. Table 4 lists eight categories that are exactly the same as, or that can be generated from, the bioclimatic data. Most of the remaining FVS categories can be generated from the CIAT datasets with varying degrees of estimated difficulty (also indicated). Thus, the CIAT data well represent the FVS categories.

For the purposes of finding species' bioclimatic thresholds, the questions that immediately follow from examining Table 4 are:

- How important is each of the listed concerns (i.e., do we really need them all?)
- Are some critical categories and need to be calculated / generated?
- Are there critical others not on our list?

In some cases, the calculation effort is easy, but the importance of the result is not. Also, it is desirable to cover any situation where the *importance* is great. To be efficient and effective, it is also desirable to avoid situations where the effort is low, but the payback is also low. So the next step is to prioritize (and possibly augment) the FVS list so that it helps to directs the next efforts. A prioritized list will be available after work on this portion of the project ends (Hayden 2011).

3.4 The concept of spatial thresholds

In the classification of zones (whether ecological, social, cultural, or otherwise), the center of a zone represents the greatest degree of hardiness. However, it is at the edges of the zones that the most diverse and dynamic activity takes place. Most often these “edges” are blurry transitions where the characteristics of two or more classifications mix and interact. An important example are estuaries, which occur when fresh water streams enter bodies of salt water. These transition areas, which are among the most biologically diverse places in the world, are absolutely critical to the health of an ecosystem. With this in mind, the climate change data were examined to identify and highlight those areas in which change occurred rapidly between two specific classifications (thresholds).

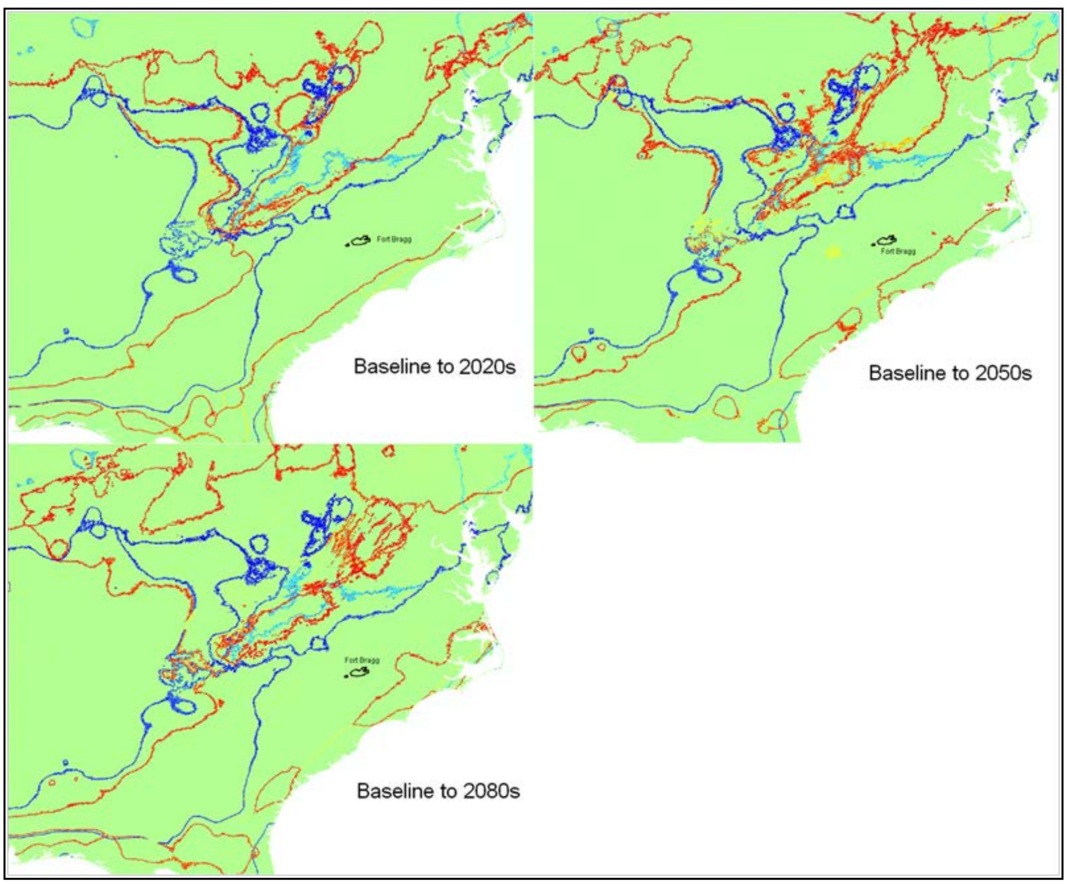
Table 4. FVS category compared to CIAT Bioclimatic category indicating the estimated Difficulty to Calculate (5=Difficult, the same data show the Difficulty = 0).

FVS #	FVS Name	CIAT #	CIAT Name, or Can It Be Generated?	Ease to Generate
1	Mean annual temperature	BIO1	Annual Mean Temperature	0
2	Average temperature in the coldest month	BIO11	Mean Temperature of Coldest Quarter (or can be derived from monthly data)	3
3	Minimum temperature in the coldest month	BIO6	Min Temperature of Coldest Month	0
4	Average temperature in the warmest month	BIO10	Mean Temperature of Warmest Quarter (or can be derived from monthly data)	0
5	Maximum temperature in the warmest month	BIO5	Max Temperature of Warmest Month	0
6	Annual precipitation	BIO12	Annual Precipitation	0
7	Growing season precipitation: April – September		Generate (Sum of Precip from April-Sept)	1
8	Summer-winter temperature differential (Variable 4 – Variable2)	BIO7	Temperature Annual Range (P5-P6)	0
9	Degree-days >5 °C		Roughly generate from monthly values >5 °C by Month	4
10	Degree-days <0 °C		Roughly generate from monthly values <0 °C by Month	4
11	Minimum temperature of degree-days <0 °C (coldest temperature)		Generated by finding coldest temperature by month	2
12	Julian Date of the last freezing date of Spring		Generated by taking the monthly trend slopes' intersection with 0 °C	5
13	Julian Date of the first freezing date of Autumn		Generated by taking the monthly trend slopes' intersection with 0 °C	5
14	Length of the frost-free period		Generate from Min Temperature by Month or FVS#13-12	1
15	Accumulated degree-days >5 °C within the frost-free period		Generate from selected monthly temps in the period FVS#12-13	3
16	Julian Date when the sum of degree-days >5 °C reaches 100		Many unclear steps	5
17	Annual dryness index: Ratio of Variable 9 to Variable 6		Easy to calculate	1
18	Summer dryness index: Ratio of Variable 15 to Variable 7		Easy to calculate	1

In one of the derivative bioclimatic layers (Bio 9 – Mean Temperature of Driest Quarter), the thresholds between classification are clearly delineated. Figure 5 shows the temporal and spatial migration of thresholds between classifications: cool colors (blues) indicate areas of stark thresholds that existed in the second half of the 20th century. Warm colors (reds, yellows) indicate the location of intense thresholds in the given projected time period (the 2020s, 2050s, and 2080s). Green areas indicate areas of classification stability.

In other layers, such as general temperature and precipitation, spatial shifts occur in a smooth gradient. Significant thresholds appear only in mountainous areas (i.e., where the threshold lines are close together in Figure 6). The location and shift of spatial thresholds can easily be calculated for minimum/maximum/mean precipitation, temperature and any of the 19 derived bioclimatic variables described in Section 3.2.5 .

Figure 6. Bio 9 threshold migration. Cool colors (blues) indicate sharp thresholds in the 20th century; warm colors (reds) indicate intense thresholds in each of the three projected future periods.



4 Dataset Characterizations

4.1 Fort Bragg data

The centroid climatic parameter from the CIAT dataset was extracted for all the data types for Fort Bragg, NC. (Appendix B to this report includes the complete dataset.)

4.2 What the CIAT Bragg data include

This work selected the following parameters for the evaluations dealing with installations:

- Limited to the installation Fort Bragg (for point centroid not including Camp MacKall Military Reservation). The same data can be accessed for anywhere in the world.
- Limited to four time snapshots:
  - o Baseline (1950-2000)
  - o 2010-2039 (the 2020s)
  - o 2040-2069 (the 2050s)
  - o 2070-2099 (the 2080s)
- Using results from six GCMs:
  - o GFDL model (NOAA Princeton): gfdl_cm2_1
  - o GISS Model e (NASA GISS): giss_model_er
  - o HadGEM1 (UKMO): ukmo_hadcm3
  - o CCCMA (Canadian model): cccma_cgcm3_1_t47
  - o CCSM3 (NCAR Boulder): ncar_ccsm3_0
  - o CSIRO (Australia): csiro_mk3_5
- Limited to three IPCC scenarios:
  - o Scenario A1b: Balance across sources
  - o Scenario A2: Regional Rapid Economic Growth
  - o Scenario B1: Global Environmental Sustainability
- Using 68 BioClimatic predictions:
  - o BIO1 = Annual Mean Temperature (deg CX10)
  - o BIO2 = Mean Diurnal Range (Mean of monthly (max temp -min temp))
  - o BIO3 = Isothermality (P2/P7) (* 100) (Mean diurnal range/temperature annual range)

- BIO4 = Temperature Seasonality (standard deviation *100) (deg CX10)
- BIO5 = Max Temperature of Warmest Month
- BIO6 = Min Temperature of Coldest Month
- BIO7 = Temperature Annual Range (P5-P6)
- BIO8 = Mean Temperature of Wettest Quarter
- BIO9 = Mean Temperature of Driest Quarter
- BIO10 = Mean Temperature of Warmest Quarter
- BIO11 = Mean Temperature of Coldest Quarter
- BIO12 = Annual Precipitation (mm)
- BIO13 = Precipitation of Wettest Month
- BIO14 = Precipitation of Driest Month
- BIO15 = Precipitation Seasonality (Coefficient of Variation)
- BIO16 = Precipitation of Wettest Quarter
- BIO17 = Precipitation of Driest Quarter
- BIO18 = Precipitation of Warmest Quarter
- BIO19 = Precipitation of Coldest Quarter
- Consecutive Months – the maximum number of consecutive dry months (<100 mm) in a year.
- Precipitation by Month
- Temperature Maximum by Month (12 predictions)
- Temperature Mean by Month (12 predictions)
- Temperature Minimum by Month (12 predictions)

4.3 Size of dataset for a location

For the installation as point data, 5544 items/point are derived from:

- 68 climate variables (minimum/maximum/mean temperature and precipitation x 12 months, 19 bioclimatic variables, one consecutive dry months calculation) for:
  - six GCMs (GFDL, GISS, UKMO, CCCMA, CCSM3, CSIRO), for:
    - three scenarios (SRES A1B, SRES A2, SRES B1), and
    - three timeframes (2010-2039 (the "2025s"), 2040-2069 (the "2055s"), and 2070-2099 (the "2085s").

There also exist in the data the same 68 climate variables for the second half of the 20th century (1950-2000) downscaled from climate station data by WorldClim and centered on 1990. (Appendix B includes all the Fort Bragg data.)

4.4 Examples of how the data can be used.

Figure 7 shows how the change in the quality of the data source has improved the data quality over that shown in Figure 4 (p 10). Although variation still exists, it is evident that the data in Figure 7 are much more directional, less random, and more reliable for their intended purpose than the previous values.

Figure 8 shows the most basic application of the climatic data at Fort Bragg, NC. The left graph shows all the GCM predictions for the “2025” time frame. Each “grouping” shows the effect of the different scenarios (A1B, A2, and B1). Each model is represented by a differently colored line. The right graph shows the same data for the next period, the “2055” time frame. (Figure 8 does not show changes between time frames.)

Applying basic statistical manipulations to the data in Figure 8 yields the simpler averaged summary (Figure 9). This average of all the models indicates that the temperature will steadily rise (black line) by nearly 3 °C. Significantly, in the near term, it will rise by a full degree by the year 2025. The standard deviation lines show that there is good agreement among all the models for all scenarios in the near term (to 2025) and that they widen as time goes on. The greatest variation between the maximum and minimum predictions is about 3.5 °C. All the lines on this graph indicate a temperature increase not less than 1.5 °C (current to 2085 minimum value). This chart reflects the expected interpretation of GCM climatic data.

One of the CIAT datasets indicated consecutive dry months – the maximum number of months during the year with less than 100 mm of rainfall. As another simple example, one may ask whether the number of consecutive dry months between the baseline and the 2025s will change. The answer to this question is a simple matter of subtracting the 2025s data (scenario A1B of the Canadian GCM) from the baseline data. Figure 10 shows the projected changes in consecutive dry months from the baseline. In Figure 10, the lighter color shows greater change. White represents an increase of 4 consecutive dry months (Camp MacKall). Most of Fort Bragg will experience an increase of 2 consecutive dry months (mid-dark grey). It is likely that this near-term change will be of interest to flora and fauna threshold research.

Figure 7. CIAT Fort Bragg temperature (x100) predictions; cf. Fig. 4.

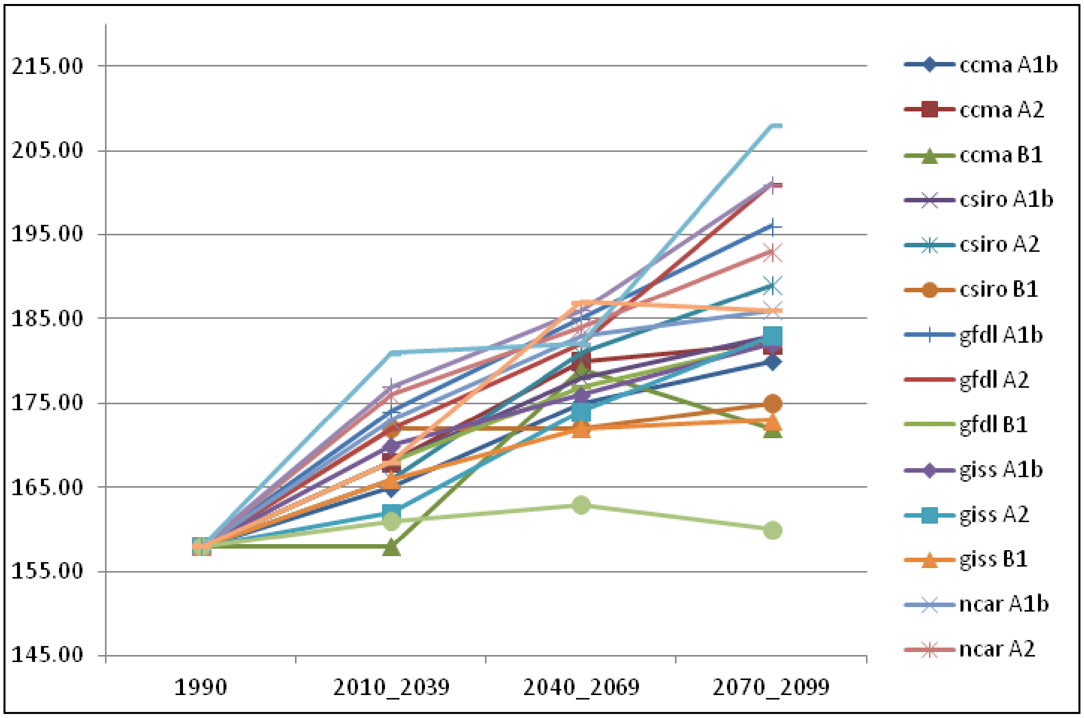


Figure 8. CIAT data displayed. On the left, Fort Bragg temperatures for "2025s"; on the right, compared to similar 2055s data.

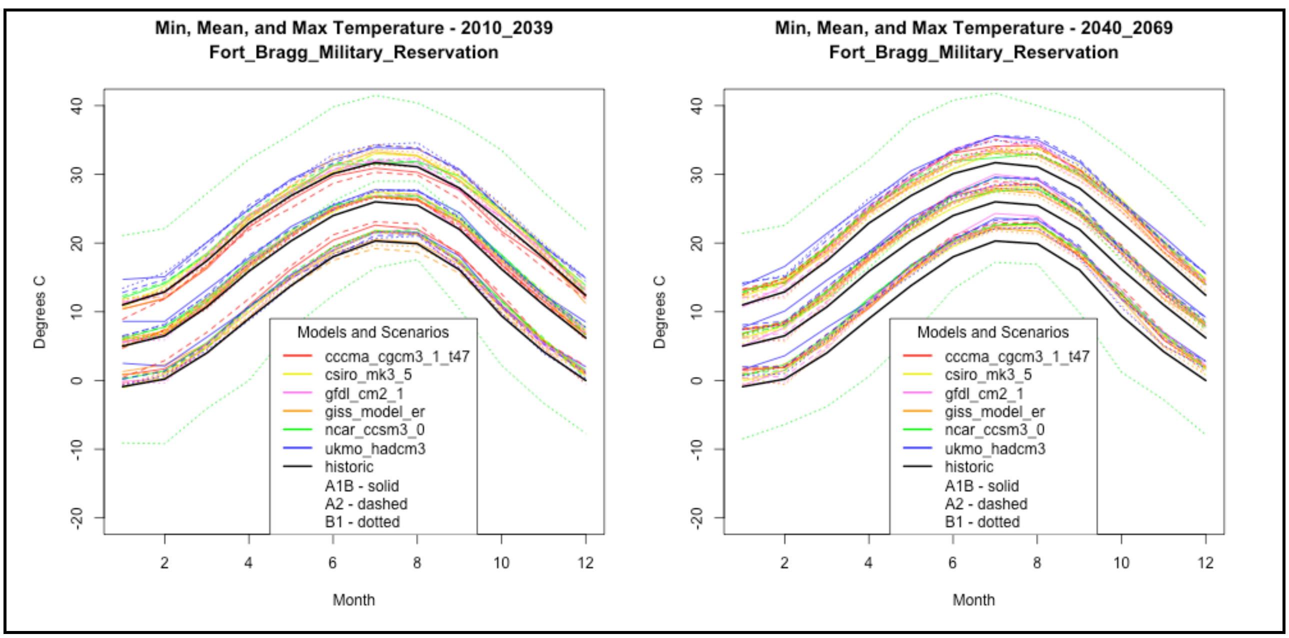


Figure 9. Bio 1 — Annual mean temperature (°C x10): average, standard deviation (SD), maximum, minimum, all GCMs and scenarios.

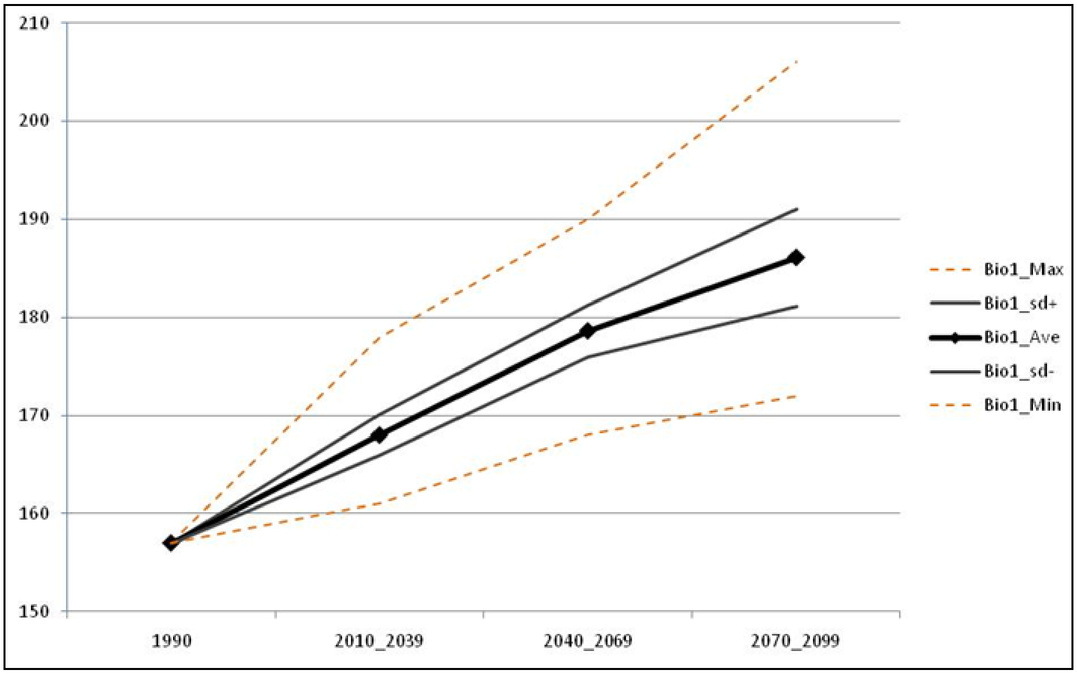
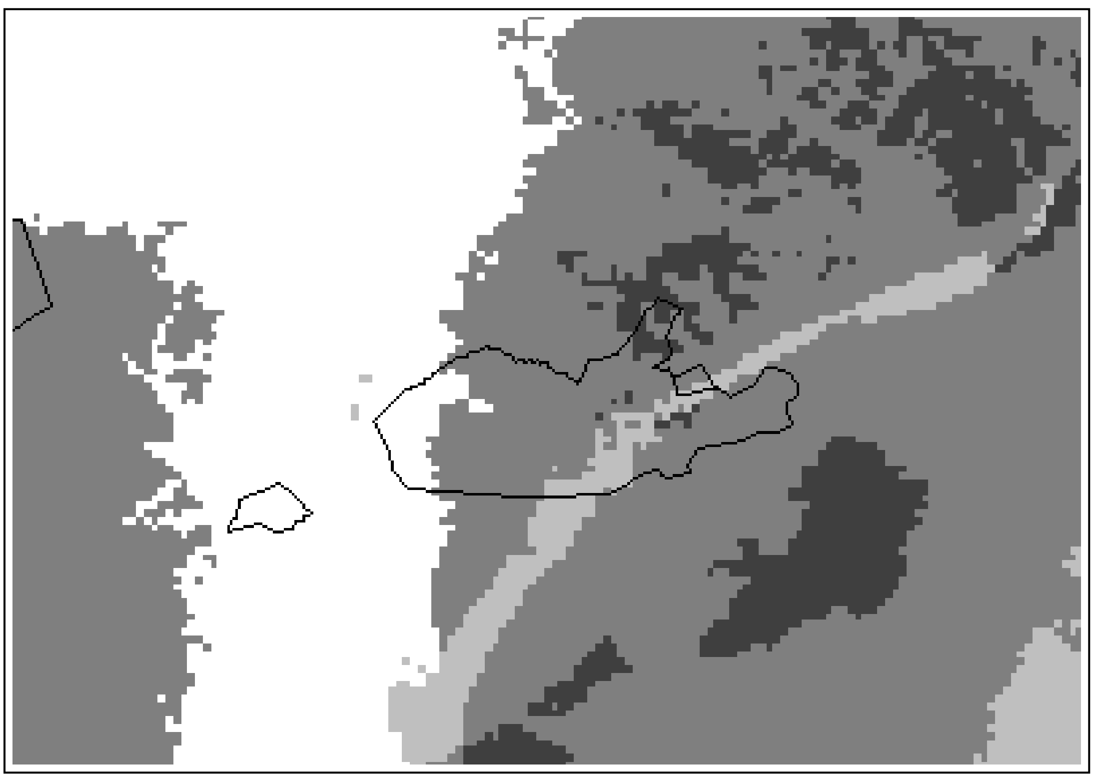


Figure 10. Increased number of consecutive dry months from 1950-2000 to the 2020s at Fort Bragg.



5 Summary and Recommendations

5.1 Summary

Based on the stated needs of the parent project, *Prediction and Adaptation of Military Natural Infrastructure in Response to Climate Change*, this work has identified the most extensive bioclimatic dataset available that has the potential to provide the data needed to determine how climatic change might affect thresholds for the survival and migration of species of interest to military land managers. These data categories, described in Section 4.2 (p 21), were generated by the *International Center for Tropical Agriculture, CIAT, Cali, Colombia*, and are now available to support the parent project.

5.2 Recommendations

This work has provided a solid foundation for the parent project to determine how climatic change might affect thresholds for the survival and migration of species of interest to military land managers. It is recommended that future work continue to:

- generate data for specific military installations
- generate spatial data over a region centered on an installation
- generate new bioclimatic data via calculations from the existing set of data
- generate spatially related threshold maps over time as the climatic parameters shift due to climatic change.
- generate the likely migration of focus species as the sister work on this project matures in determining thresholds per species, including the:
    - migration of focus species off an installation
    - migration of focus (likely invasive species) onto an installation
- address broader concerns specifically related to military specific issues, such as:
    - viability of current training lands over time
    - problems of increasing erosion on military lands
    - identification of new military lands in the CONUS similar to focus lands elsewhere in the world
    - long-term viability of Military missions at different installations as climatic factors change.

Acronyms and Abbreviations

Term	Definition
BCC	Beijing Climate Center
BCCR	Bjerknes Centre for Climate Research
CCAFS	Climate Change Agriculture and Food Security
CCCma	Canadian Center for Climate Modelling and Analysis
CEERD	US Army Corps of Engineers, Engineer Research and Development Center
CEQ	Council on Environmental Quality
CERL	Construction Engineering Research Laboratory
CIAT	International Center for Tropical Agriculture (CIAT, Centro Internacional de Agricultura Tropical, Cali, Colombia)
CNRM	Centre National de Recherches Meteorologiques
CONUS	Continental United States
CSIRO	Australia's Commonwealth Scientific and Industrial Research Organization
ERDC	Engineer Research and Development Center
FVS	Forest Vegetation Simulator
GCM	Global Climate Model
GFDL	Geophysical Fluid Dynamics Laboratory
GHG	Greenhouse Gas
GISS	Goddard Institute for Space Studies
INGV	National Institute of Geophysics and Volcanology
INM	Institute for Numerical Mathematics
IPCC	Intergovernmental Panel on Climate Change
IPSL	Institut Pierre-Simon Laplace
LASG	Institute of Atmospheric Physics
M&D	Model and Data Groupe at MPI-M
METRI	Meteorological Research Institute of KMA
MIUB	Meteorological Institute, University of Bonn
MPI-M	Max-Planck-Institut for Meteorology
MRI	Meteorological Research Institute
NCAR	National Center for Atmospheric Research
NEPA	National Environmental Policy Act
NIES	National Institute for Environmental Studies
NIS	Noxious Invasive Species
OSD	Office of the Secretary of Defense
SD	Standard Deviation
SF	standard form
SRES	The Special Report on Emissions Scenarios

Term	**Definition**
TAR	Third Assessment Report
TES	Threatened and Endangered Species
TR	Technical Report
UK	United Kingdom
UKMO	UK Met Office [Hadley Centre]
URL	Universal Resource Locator
USA	United States of America
WWW	World Wide Web

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Appendix A: FVS Climate Attributes for Fort Irwin, CA

Table A1. FVS climate attributes for Fort Irwin, CA.

		Mean Annual Temp	Mean Annual Precip	Growing Season Precip	Min Temp Coldest Month	Min Temp of degree-days <0 °C	Max Temp Warmest Month	Summer-Winter Temp Differential		Frost-Free Period	Degree-Days > 5 °C	Accum Degree-Days >5 °C within ffp	Julian Date When the Sum of Degree-Days >5 °C Reaches 100	Degree-Days < 0 °C	
Scenario	Year	mat	map	gsp	mtcm	mmin	mtwm	mmax	sday	ffp	dd5	gsdd5	d100	dd0	pSite
CGCM3_A1B	1990	22.1	76	26	9.9	1.9	34.5	43.3	41	294	6234	5858	19	0	0
CGCM3_A1B	2030	23.9	87	27	11.6	3.9	35.9	44.5	12	346	6905	6767	13	0	0
CGCM3_A1B	2060	24.9	76	25	12.1	4.5	37	45.5	10	357	7270	7171	13	0	0
CGCM3_A1B	2090	25.8	73	19	13.2	5.2	38.4	47	12	351	7580	7431	11	0	0
CGCM3_A2	1990	22.1	76	26	9.9	1.9	34.5	43.3	41	294	6234	5858	19	0	0
CGCM3_A2	2030	23.6	82	28	10.9	3.5	36.4	45.2	10	341	6801	6673	15	0	0
CGCM3_A2	2060	25.3	77	34	13	4.9	37.5	46.1	9	357	7378	7274	12	0	0
CGCM3_A2	2090	27.1	48	18	14.1	5.8	38.8	47.3	16	346	8037	7845	11	0	0
CGCM3_B1	1990	22.1	76	26	9.9	1.9	34.5	43.3	41	294	6234	5858	19	0	0
CGCM3_B1	2030	24	76	23	11.4	3.5	36.9	45.8	23	328	6952	6688	12	0	0
CGCM3_B1	2060	24.4	73	20	12.2	4.5	36.8	45.5	17	343	7082	6896	13	0	0
CGCM3_B1	2090	24.7	77	23	12.5	4.6	37.4	45.9	9	357	7197	7097	13	0	0
GFDLCM21_A2	1990	22.1	76	26	9.9	1.9	34.5	43.3	41	294	6234	5858	19	0	0
GFDLCM21_A2	2030	23.9	76	23	10.4	2.6	37	45.7	20	329	6903	6698	16	0	0
GFDLCM21_A2	2060	25	75	19	12.6	4.6	38.5	47.1	17	342	7293	7087	13	0	0
GFDLCM21_A2	2090	27.3	46	17	13.4	5.1	41.2	49.9	16	348	8115	7919	12	0	0
GFDLCM21_B1	1990	22.1	76	26	9.9	1.9	34.5	43.3	41	294	6234	5858	19	0	0
GFDLCM21_B1	2030	23.6	68	21	11.3	3.4	36.4	45.3	30	317	6804	6478	15	0	0
GFDLCM21_B1	2060	24.4	64	20	12.1	4.1	37.1	45.9	23	334	7093	6828	13	0	0
GFDLCM21_B1	2090	24.7	75	25	11.3	3.3	38.1	46.9	21	337	7190	6963	13	0	0
HADCM3_A2	1990	22.1	76	26	9.9	1.9	34.5	43.3	41	294	6234	5858	19	0	0
HADCM3_A2	2030	23.6	86	30	10.8	2.7	36.5	45	19	334	6792	6598	15	0	0

		Mean Annual Temp	Mean Annual Precip	Growing Season Precip	Min Temp Coldest Month	Min Temp of degree-days <0 °C	Max Temp Warmest Month	Summer-Winter Temp Differential		Frost-Free Period	Degree-Days > 5 °C	Accum Degree-Days >5 °C within ffp	Julian Date When the Sum of Degree-Days >5 °C Reaches 100	Degree-Days < 0 °C	
Scenario	Year	mat	map	gsp	mtcm	mmin	mtwm	mmax	sday	ffp	dd5	gsdd5	d100	dd0	pSite
HADCM3_A2	2060	25.1	133	73	12.1	3.7	38.9	47.1	21	331	7327	7074	14	0	0
HADCM3_A2	2090	27.2	114	65	13.2	4.8	41.5	49.5	13	344	8084	7917	12	0	0
HADCM3_B2	1990	22.1	76	26	9.9	1.9	34.5	43.3	41	294	6234	5858	19	0	0
HADCM3_B2	2030	23.9	90	40	11.4	2.9	36.5	45.3	27	324	6903	6644	15	0	0
HADCM3_B2	2060	24.9	116	64	11.8	3.5	37.9	46.7	21	329	7277	7023	13	0	0
HADCM3_B2	2090	25.4	140	75	13	4	38.2	47	15	343	7455	7268	12	0	0

Note that the data distributed has abbreviations as column headers. The extended description is a guess as to what the abbreviations mean. The web site lists 18 variables as output, but only 14 columns of climatic parameters are present in the output. Other columns were present in the output associated with different tree species; they are not included in this table.

Appendix B: CIAT Dataset for Fort Bragg, NC

Table B1. CIAT dataset for Fort Bragg, NC.

Fort Bragg Centroid				Year			
Model	Scenario	Theme	Month	1990	2010–2039	2040–2069	2070–2099
cccma_cgcm3_1_t47							
	A1B						
		bio					
			1	157	164	180	178
			2	126	100	126	97
			3	38	33	38	31
			4	7464	7652	7793	7806
			5	315	307	341	321
			6	-10	7	14	9
			7	325	300	327	312
			8	250	259	278	276
			9	110	171	186	183
			10	250	259	278	276
			11	58	63	77	75
			12	1194	1280	1313	1300
			13	148	150	162	156
			14	71	76	77	77
			15	21	19	23	22
			16	394	415	443	423
			17	235	258	265	261
			18	394	415	443	423
			19	272	312	328	324
			cons_mths	272	312	328	324
		prec					
			1	91	192	204	170
			2	99	206	214	248
			3	104	196	202	216
			4	80	192	164	172
			5	93	202	188	196
			6	117	266	266	256
			7	148	300	324	312
			8	129	264	296	278
			9	98	198	204	210
			10	82	152	154	154
			11	71	166	172	158
			12	82	226	238	230
		tmax					
			1	110	104	132	107

Fort Bragg Centroid				Year			
Model	Scenario	Theme	Month	1990	2010–2039	2040–2069	2070–2099
			2	128	118	141	143
			3	173	163	192	180
			4	228	222	245	234
			5	269	263	295	277
			6	300	296	330	315
			7	315	307	339	321
			8	310	302	341	319
			9	280	277	306	284
			10	228	215	256	230
			11	176	173	191	181
			12	124	122	141	129
		tmean					
			1	50	56	73	58
			2	64	67	80	93
			3	106	108	127	127
			4	158	165	175	180
			5	203	213	227	228
			6	240	250	269	271
			7	258	266	281	280
			8	254	261	285	278
			9	221	232	244	241
			10	160	167	191	185
			11	108	115	125	124
			12	62	67	80	76
		tmin					
			1	-10	7	14	9
			2	1	16	18	42
			3	40	53	62	74
			4	89	108	104	125
			5	138	162	159	179
			6	180	204	207	227
			7	202	225	223	239
			8	198	219	229	236
			9	162	186	181	197
			10	93	118	125	139
			11	41	56	58	66
			12	0	12	19	22
	A2						
		bio					
			1	157	164	184	186
			2	126	87	124	86
			3	38	29	37	29
			4	7464	7598	7789	7797
			5	315	301	349	325

Fort Bragg Centroid		Theme	Month	Year			
Model	Scenario			1990	2010–2039	2040–2069	2070–2099
			6	-10	3	15	30
			7	325	298	334	295
			8	250	259	281	283
			9	110	167	181	196
			10	250	259	281	283
			11	58	63	80	82
			12	1194	1274	1241	1325
			13	148	155	150	157
			14	71	71	76	84
			15	21	25	22	21
			16	394	431	418	430
			17	235	264	262	274
			18	394	431	418	430
			19	272	309	295	330
			cons_mths	272	309	295	330
		prec					
			1	91	158	176	172
			2	99	212	192	230
			3	104	198	202	200
			4	80	160	170	182
			5	93	182	152	200
			6	117	274	260	244
			7	148	310	300	314
			8	129	278	276	302
			9	98	230	192	200
			10	82	156	164	168
			11	71	142	176	180
			12	82	248	222	258
		tmax					
			1	110	89	133	116
			2	128	118	147	139
			3	173	166	196	176
			4	228	218	250	231
			5	269	251	299	280
			6	300	286	331	309
			7	315	301	349	325
			8	310	298	337	321
			9	280	264	307	288
			10	228	211	255	239
			11	176	162	194	195
			12	124	119	145	130
		tmean					
			1	50	46	74	73
			2	64	73	83	94

Fort Bragg Centroid				Year			
Model	Scenario	Theme	Month	1990	2010–2039	2040–2069	2070–2099
			3	106	118	132	129
			4	158	168	180	182
			5	203	209	233	239
			6	240	249	271	273
			7	258	266	289	291
			8	254	263	283	286
			9	221	224	247	249
			10	160	168	195	197
			11	108	109	132	142
			12	62	70	83	81
		tmin					
			1	-10	3	15	30
			2	1	28	18	49
			3	40	70	67	81
			4	89	118	110	133
			5	138	167	167	197
			6	180	212	211	236
			7	202	230	228	256
			8	198	227	229	250
			9	162	183	186	209
			10	93	125	135	154
			11	41	56	70	88
			12	0	21	21	32
	B1						
		bio					
			1	157	161	176	172
			2	126	116	124	112
			3	38	36	37	35
			4	7464	7709	7707	7600
			5	315	312	336	319
			6	-10	-7	7	-1
			7	325	319	329	320
			8	250	258	272	266
			9	110	111	182	171
			10	250	258	272	266
			11	58	60	75	70
			12	1194	1302	1303	1307
			13	148	153	168	160
			14	71	87	83	77
			15	21	19	24	21
			16	394	422	435	416
			17	235	276	268	284
			18	394	422	435	416
			19	272	298	306	322

Fort Bragg Centroid				Year			
Model	Scenario	Theme	Month	1990	2010–2039	2040–2069	2070–2099
			cons_mths	272	298	306	322
		prec					
			1	91	198	172	172
			2	99	198	194	244
			3	104	238	246	228
			4	80	180	166	154
			5	93	180	176	186
			6	117	250	256	236
			7	148	306	336	320
			8	129	288	278	276
			9	98	214	194	206
			10	82	174	172	162
			11	71	178	170	202
			12	82	200	246	228
		tmax					
			1	110	109	125	112
			2	128	131	148	141
			3	173	167	188	184
			4	228	224	249	236
			5	269	267	288	274
			6	300	300	323	307
			7	315	312	336	319
			8	310	310	330	317
			9	280	280	301	283
			10	228	220	244	234
			11	176	180	185	186
			12	124	122	140	134
		tmean					
			1	50	51	66	56
			2	64	71	84	83
			3	106	103	122	123
			4	158	158	179	172
			5	203	209	224	218
			6	240	248	264	257
			7	258	264	278	273
			8	254	262	276	270
			9	221	227	242	233
			10	160	163	184	180
			11	108	113	122	121
			12	62	59	76	72
		tmin					
			1	-10	-7	7	-1
			2	1	10	19	25
			3	40	39	56	61

Fort Bragg Centroid		Theme	Month	Year			
Model	Scenario			1990	2010–2039	2040–2069	2070–2099
			4	89	91	108	108
			5	138	151	160	162
			6	180	195	205	207
			7	202	216	220	226
			8	198	213	221	223
			9	162	173	183	183
			10	93	105	124	126
			11	41	46	59	56
			12	0	-5	12	10
csiro_mk3_5							
	A1B						
		bio					
			1	157	168	177	186
			2	126	125	125	124
			3	38	36	36	36
			4	7464	7756	7657	7835
			5	315	329	337	348
			6	-10	-12	-2	7
			7	325	341	339	341
			8	250	262	249	259
			9	110	123	190	144
			10	250	262	270	283
			11	58	63	74	82
			12	1194	1221	1269	1249
			13	148	154	164	157
			14	71	78	74	64
			15	21	22	23	27
			16	394	411	416	417
			17	235	249	247	209
			18	394	411	407	343
			19	272	272	275	262
			cons_mths	272	272	275	262
		prec					
			1	91	194	176	174
			2	99	184	196	196
			3	104	192	246	280
			4	80	162	200	224
			5	93	196	234	276
			6	117	272	270	244
			7	148	308	328	314
			8	129	242	216	178
			9	98	194	174	194
			10	82	176	172	128
			11	71	156	148	136

Fort Bragg Centroid		Theme	Month	Year			
Model	Scenario			1990	2010–2039	2040–2069	2070–2099
			12	82	166	178	154
		tmax					
			1	110	106	122	132
			2	128	137	144	147
			3	173	181	193	193
			4	228	237	244	247
			5	269	282	281	284
			6	300	301	306	314
			7	315	329	331	348
			8	310	326	337	348
			9	280	292	308	325
			10	228	243	262	265
			11	176	189	198	210
			12	124	133	148	161
		tmean					
			1	50	47	60	70
			2	64	73	79	83
			3	106	114	127	130
			4	158	168	178	183
			5	203	217	220	226
			6	240	245	251	259
			7	258	273	278	294
			8	254	270	281	291
			9	221	233	248	266
			10	160	177	192	197
			11	108	124	131	143
			12	62	70	83	94
		tmin					
			1	-10	-12	-2	7
			2	1	8	14	19
			3	40	47	61	67
			4	89	99	111	118
			5	138	152	158	168
			6	180	188	195	204
			7	202	216	224	239
			8	198	213	224	233
			9	162	174	188	206
			10	93	110	121	128
			11	41	58	63	75
			12	0	6	18	26
	A2						
		bio					
			1	157	168	179	193
			2	126	126	125	127

Fort Bragg Centroid				Year			
Model	Scenario	Theme	Month	1990	2010–2039	2040–2069	2070–2099
			3	38	37	37	34
			4	7464	7641	7851	8266
			5	315	329	337	368
			6	-10	-4	1	4
			7	325	333	336	364
			8	250	262	254	270
			9	110	123	135	150
			10	250	262	273	294
			11	58	65	73	83
			12	1194	1230	1223	1158
			13	148	141	156	143
			14	71	67	59	62
			15	21	19	26	24
			16	394	386	406	355
			17	235	238	204	207
			18	394	386	390	336
			19	272	293	293	260
			cons_mths	272	293	293	260
		prec					
			1	91	198	194	178
			2	99	216	230	200
			3	104	222	220	262
			4	80	198	186	222
			5	93	204	252	204
			6	117	268	248	220
			7	148	282	312	286
			8	129	222	220	166
			9	98	174	176	164
			10	82	134	118	148
			11	71	170	128	124
			12	82	172	162	142
		tmax					
			1	110	118	125	134
			2	128	129	138	155
			3	173	183	188	194
			4	228	232	247	255
			5	269	275	286	300
			6	300	302	313	331
			7	315	329	337	355
			8	310	326	336	368
			9	280	298	315	331
			10	228	242	261	276
			11	176	191	201	218
			12	124	137	148	160

Fort Bragg Centroid				Year			
Model	Scenario	Theme	Month	1990	2010–2039	2040–2069	2070–2099
		tmean					
			1	50	57	63	69
			2	64	66	74	89
			3	106	117	123	128
			4	158	166	181	189
			5	203	213	225	237
			6	240	246	257	274
			7	258	272	282	300
			8	254	269	280	308
			9	221	236	255	271
			10	160	172	190	209
			11	108	124	134	150
			12	62	73	82	92
		tmin					
			1	-10	-4	1	4
			2	1	2	10	23
			3	40	51	58	62
			4	89	99	114	123
			5	138	150	164	174
			6	180	190	200	216
			7	202	214	227	244
			8	198	211	223	247
			9	162	173	195	210
			10	93	101	119	141
			11	41	56	66	81
			12	0	8	16	24
	B1						
		bio					
			1	157	169	173	179
			2	126	127	124	127
			3	38	36	36	36
			4	7464	7688	7693	7946
			5	315	334	329	348
			6	-10	-10	-8	1
			7	325	344	337	347
			8	250	245	266	255
			9	110	126	130	132
			10	250	264	266	278
			11	58	65	69	73
			12	1194	1135	1281	1180
			13	148	140	163	133
			14	71	63	69	64
			15	21	23	23	21
			16	394	372	417	378

Fort Bragg Centroid		Theme	Month	Year			
Model	Scenario			1990	2010–2039	2040–2069	2070–2099
			17	235	214	238	218
			18	394	348	417	352
			19	272	257	276	264
			cons_mths	272	257	276	264
		prec					
			1	91	170	168	196
			2	99	168	218	170
			3	104	220	236	228
			4	80	164	216	206
			5	93	246	224	226
			6	117	218	262	264
			7	148	280	326	266
			8	129	198	246	174
			9	98	178	190	194
			10	82	126	138	146
			11	71	126	172	128
			12	82	176	166	162
		tmax					
			1	110	114	115	127
			2	128	133	145	141
			3	173	183	182	191
			4	228	240	236	242
			5	269	274	275	284
			6	300	303	308	314
			7	315	334	329	343
			8	310	328	327	348
			9	280	297	303	311
			10	228	242	256	254
			11	176	199	196	201
			12	124	143	139	148
		tmean					
			1	50	52	54	64
			2	64	68	80	76
			3	106	116	119	125
			4	158	172	172	175
			5	203	213	214	222
			6	240	246	251	258
			7	258	276	275	287
			8	254	270	273	289
			9	221	237	245	251
			10	160	172	187	186
			11	108	129	129	131
			12	62	77	74	81
		tmin					

Fort Bragg Centroid				Year			
Model	Scenario	Theme	Month	1990	2010–2039	2040–2069	2070–2099
			1	-10	-10	-8	1
			2	1	3	15	10
			3	40	49	55	58
			4	89	103	108	108
			5	138	151	153	159
			6	180	188	194	202
			7	202	218	220	231
			8	198	211	218	229
			9	162	177	187	191
			10	93	102	117	118
			11	41	59	61	61
			12	0	10	8	13
gfdl_cm2_1							
	A1B						
		bio					
			1	157	165	182	191
			2	126	120	122	119
			3	38	37	33	32
			4	7464	7517	8400	8464
			5	315	317	354	365
			6	-10	-2	-8	0
			7	325	319	362	365
			8	250	259	287	295
			9	110	169	134	137
			10	250	259	287	295
			11	58	64	69	77
			12	1194	1321	1313	1363
			13	148	182	176	165
			14	71	76	81	89
			15	21	28	25	21
			16	394	480	446	453
			17	235	257	257	289
			18	394	480	446	453
			19	272	281	288	308
			cons_mths	272	281	288	308
		prec					
			1	91	206	222	228
			2	99	166	182	178
			3	104	210	232	204
			4	80	194	194	196
			5	93	202	172	188
			6	117	282	230	282
			7	148	364	310	330
			8	129	314	352	294

Fort Bragg Centroid				Year			
Model	Scenario	Theme	Month	1990	2010–2039	2040–2069	2070–2099
			9	98	168	218	240
			10	82	194	162	188
			11	71	152	180	188
			12	82	190	172	210
		tmax					
			1	110	112	107	119
			2	128	127	138	141
			3	173	179	189	197
			4	228	241	253	261
			5	269	275	293	299
			6	300	305	335	334
			7	315	317	354	356
			8	310	315	344	365
			9	280	276	301	314
			10	228	236	256	265
			11	176	187	197	203
			12	124	131	140	150
		tmean					
			1	50	55	50	60
			2	64	64	76	80
			3	106	116	126	135
			4	158	174	185	196
			5	203	214	230	238
			6	240	248	272	276
			7	258	267	298	302
			8	254	264	291	309
			9	221	219	246	261
			10	160	171	193	203
			11	108	119	130	138
			12	62	73	81	92
		tmin					
			1	-10	-2	-8	0
			2	1	0	14	19
			3	40	52	62	72
			4	89	106	116	130
			5	138	152	166	177
			6	180	190	209	217
			7	202	216	242	248
			8	198	212	238	253
			9	162	162	190	207
			10	93	106	130	141
			11	41	51	63	73
			12	0	14	22	34
	A2						

Fort Bragg Centroid				Year			
Model	Scenario	Theme	Month	1990	2010–2039	2040–2069	2070–2099
		bio					
			1	157	166	179	198
			2	126	120	122	121
			3	38	36	35	34
			4	7464	7644	8067	8445
			5	315	321	348	368
			6	-10	-5	3	18
			7	325	326	345	350
			8	250	262	278	303
			9	110	121	137	198
			10	250	262	278	303
			11	58	64	71	83
			12	1194	1340	1313	1303
			13	148	177	164	163
			14	71	71	87	61
			15	21	26	19	25
			16	394	465	423	441
			17	235	250	289	257
			18	394	465	423	441
			19	272	291	291	310
			cons_mths	272	291	291	310
		prec					
			1	91	216	220	246
			2	99	186	188	198
			3	104	210	210	208
			4	80	220	184	122
			5	93	192	196	184
			6	117	262	238	260
			7	148	354	328	326
			8	129	314	280	296
			9	98	226	204	198
			10	82	178	204	186
			11	71	142	200	206
			12	82	180	174	176
		tmax					
			1	110	114	120	133
			2	128	128	131	143
			3	173	176	179	207
			4	228	240	249	268
			5	269	272	287	312
			6	300	307	319	347
			7	315	318	337	366
			8	310	321	348	368
			9	280	280	302	316

Fort Bragg Centroid		Theme	Month	Year			
Model	Scenario			1990	2010–2039	2040–2069	2070–2099
			10	228	235	256	272
			11	176	189	201	213
			12	124	130	142	151
		tmean					
			1	50	55	62	76
			2	64	67	68	81
			3	106	111	115	145
			4	158	172	182	201
			5	203	210	225	248
			6	240	250	259	286
			7	258	267	283	311
			8	254	270	293	314
			9	221	227	246	262
			10	160	173	193	208
			11	108	122	135	148
			12	62	70	84	93
		tmin					
			1	-10	-5	3	18
			2	1	5	5	19
			3	40	46	50	82
			4	89	104	114	133
			5	138	148	162	184
			6	180	192	199	225
			7	202	215	229	256
			8	198	219	238	259
			9	162	174	189	207
			10	93	111	129	144
			11	41	54	69	82
			12	0	9	25	34
	B1						
		bio					
			1	157	167	172	179
			2	126	122	122	122
			3	38	37	35	34
			4	7464	7660	8005	7957
			5	315	323	333	339
			6	-10	-5	-6	-15
			7	325	328	339	354
			8	250	259	270	275
			9	110	84	133	190
			10	250	262	270	275
			11	58	63	62	69
			12	1194	1302	1313	1328
			13	148	170	164	162

Fort Bragg Centroid				Year			
Model	Scenario	Theme	Month	1990	2010–2039	2040–2069	2070–2099
			14	71	84	82	87
			15	21	23	27	22
			16	394	437	475	452
			17	235	261	267	277
			18	394	437	475	452
			19	272	271	280	303
			cons_mths	272	271	280	303
		prec					
			1	91	178	200	218
			2	99	188	164	176
			3	104	200	208	206
			4	80	202	196	208
			5	93	182	174	178
			6	117	248	322	268
			7	148	340	328	324
			8	129	286	300	312
			9	98	196	200	174
			10	82	240	170	194
			11	71	168	168	186
			12	82	176	196	212
		tmax					
			1	110	115	109	103
			2	128	121	122	144
			3	173	184	176	197
			4	228	237	244	249
			5	269	274	281	287
			6	300	312	315	320
			7	315	319	333	339
			8	310	323	328	334
			9	280	289	291	301
			10	228	233	254	262
			11	176	185	206	200
			12	124	134	135	139
		tmean					
			1	50	56	52	44
			2	64	58	59	83
			3	106	120	111	133
			4	158	168	177	182
			5	203	211	218	225
			6	240	252	258	261
			7	258	266	279	284
			8	254	269	275	281
			9	221	232	234	243
			10	160	170	186	194

Fort Bragg Centroid				Year			
Model	Scenario	Theme	Month	1990	2010–2039	2040–2069	2070–2099
			11	108	119	138	134
			12	62	77	76	80
		tmin					
			1	-10	-3	-6	-15
			2	1	-5	-4	21
			3	40	55	46	69
			4	89	98	110	114
			5	138	147	155	162
			6	180	191	200	202
			7	202	213	225	228
			8	198	215	221	228
			9	162	174	176	184
			10	93	106	118	125
			11	41	52	70	67
			12	0	20	17	21
giss_model_er							
	A1B						
		bio					
			1	157	165	175	179
			2	126	118	122	118
			3	38	36	38	37
			4	7464	7627	7518	7537
			5	315	330	331	341
			6	-10	10	18	27
			7	325	320	313	314
			8	250	259	269	272
			9	110	79	78	96
			10	250	259	269	272
			11	58	63	78	78
			12	1194	1246	1352	1441
			13	148	171	183	193
			14	71	77	86	94
			15	21	26	23	24
			16	394	424	444	489
			17	235	242	280	288
			18	394	424	444	489
			19	272	260	280	309
			cons_mths	272	260	280	309
		prec					
			1	91	154	172	192
			2	99	190	196	230
			3	104	240	262	270
			4	80	170	200	222
			5	93	178	190	198

Fort Bragg Centroid		Theme	Month	Year			
Model	Scenario			1990	2010–2039	2040–2069	2070–2099
			6	117	250	260	288
			7	148	342	366	386
			8	129	256	262	304
			9	98	216	212	214
			10	82	166	194	194
			11	71	154	198	188
			12	82	176	192	196
		tmax					
			1	110	104	130	125
			2	128	119	143	124
			3	173	164	184	180
			4	228	234	243	246
			5	269	276	283	291
			6	300	311	318	327
			7	315	330	331	341
			8	310	325	327	339
			9	280	291	296	303
			10	228	238	250	255
			11	176	181	185	192
			12	124	112	139	130
		tmean					
			1	50	58	74	79
			2	64	71	81	76
			3	106	109	119	125
			4	158	170	176	182
			5	203	212	221	227
			6	240	248	260	264
			7	258	267	276	277
			8	254	263	272	275
			9	221	231	240	242
			10	160	172	184	190
			11	108	120	117	130
			12	62	61	80	80
		tmin					
			1	-10	12	18	33
			2	1	22	18	27
			3	40	54	54	70
			4	89	105	108	117
			5	138	148	158	162
			6	180	185	201	200
			7	202	204	220	212
			8	198	200	216	210
			9	162	170	183	181
			10	93	106	117	124

Fort Bragg Centroid				Year			
Model	Scenario	Theme	Month	1990	2010–2039	2040–2069	2070–2099
			11	41	59	49	68
			12	0	10	21	29
	A2						
		bio					
			1	157	165	176	186
			2	126	137	123	137
			3	38	41	37	41
			4	7464	7521	7454	7460
			5	315	341	334	359
			6	-10	8	10	29
			7	325	333	324	330
			8	250	259	269	278
			9	110	82	92	104
			10	250	259	269	278
			11	58	65	78	86
			12	1194	1292	1325	1434
			13	148	167	172	200
			14	71	73	86	85
			15	21	25	22	25
			16	394	439	442	479
			17	235	241	275	284
			18	394	439	442	479
			19	272	274	281	312
			cons_mths	272	274	281	312
		prec					
			1	91	170	172	188
			2	99	212	200	226
			3	104	244	232	284
			4	80	180	202	208
			5	93	178	180	192
			6	117	270	262	276
			7	148	334	344	400
			8	129	274	278	282
			9	98	236	224	226
			10	82	174	178	206
			11	71	146	188	170
			12	82	166	190	210
		tmax					
			1	110	111	125	134
			2	128	123	149	142
			3	173	175	187	197
			4	228	234	241	256
			5	269	284	285	309
			6	300	323	318	344

Fort Bragg Centroid				Year			
Model	Scenario	Theme	Month	1990	2010–2039	2040–2069	2070–2099
			7	315	341	334	359
			8	310	337	326	355
			9	280	303	299	320
			10	228	251	250	272
			11	176	192	195	211
			12	124	125	141	150
		tmean					
			1	50	60	68	82
			2	64	68	86	86
			3	106	112	122	134
			4	158	162	174	183
			5	203	211	221	235
			6	240	249	259	271
			7	258	266	278	285
			8	254	262	271	279
			9	221	230	242	248
			10	160	174	184	196
			11	108	121	129	139
			12	62	67	81	91
		tmin					
			1	-10	8	10	30
			2	1	12	23	29
			3	40	49	57	70
			4	89	89	106	110
			5	138	137	157	161
			6	180	175	200	198
			7	202	191	221	210
			8	198	186	216	203
			9	162	157	185	175
			10	93	97	118	119
			11	41	49	63	66
			12	0	9	20	32
	B1						
		bio					
			1	157	165	168	172
			2	126	133	123	132
			3	38	40	36	40
			4	7464	7544	7907	7579
			5	315	334	328	343
			6	-10	8	-7	15
			7	325	326	335	328
			8	250	259	265	267
			9	110	81	120	88
			10	250	259	265	267

Fort Bragg Centroid		Theme	Month	Year			
Model	Scenario			1990	2010–2039	2040–2069	2070–2099
			11	58	66	62	72
			12	1194	1241	1301	1323
			13	148	171	170	178
			14	71	75	78	82
			15	21	27	25	23
			16	394	442	451	445
			17	235	244	248	279
			18	394	442	451	445
			19	272	260	277	284
			cons_mths	272	260	277	284
		prec					
			1	91	154	166	196
			2	99	190	212	174
			3	104	218	242	236
			4	80	150	208	196
			5	93	170	176	190
			6	117	272	280	276
			7	148	342	340	356
			8	129	270	282	258
			9	98	206	200	202
			10	82	176	164	200
			11	71	158	156	164
			12	82	176	176	198
		tmax					
			1	110	118	121	123
			2	128	127	119	129
			3	173	176	179	182
			4	228	239	238	245
			5	269	283	282	290
			6	300	319	315	326
			7	315	334	328	343
			8	310	331	321	337
			9	280	299	291	301
			10	228	245	243	255
			11	176	183	183	187
			12	124	126	130	134
		tmean					
			1	50	63	62	70
			2	64	69	56	72
			3	106	112	113	119
			4	158	166	172	173
			5	203	213	219	220
			6	240	250	256	258
			7	258	265	273	274

Fort Bragg Centroid		Theme	Month	Year			
Model	Scenario			1990	2010–2039	2040–2069	2070–2099
			8	254	263	267	269
			9	221	232	234	235
			10	160	171	176	182
			11	108	114	115	118
			12	62	67	69	76
		tmin					
			1	-10	8	3	16
			2	1	10	-7	15
			3	40	48	47	55
			4	89	93	105	101
			5	138	142	155	149
			6	180	181	197	189
			7	202	196	217	204
			8	198	194	212	200
			9	162	164	176	168
			10	93	97	109	109
			11	41	45	47	49
			12	0	8	8	17
ncar_ccsm3_0							
	A1B						
		bio					
			1	157	171	179	184
			2	126	121	120	121
			3	38	38	37	37
			4	7464	7403	7537	7537
			5	315	318	329	331
			6	-10	1	6	9
			7	325	317	323	322
			8	250	262	270	277
			9	110	127	134	137
			10	250	262	270	277
			11	58	71	77	79
			12	1194	1333	1377	1381
			13	148	187	196	193
			14	71	76	76	76
			15	21	28	28	28
			16	394	468	490	484
			17	235	243	257	255
			18	394	468	490	484
			19	272	281	289	276
			cons_mths	272	281	289	276
		prec					
			1	91	206	186	212
			2	99	204	206	188

Fort Bragg Centroid		Theme	Month	Year			
Model	Scenario			1990	2010–2039	2040–2069	2070–2099
			3	104	230	208	232
			4	80	168	194	182
			5	93	246	244	246
			6	117	246	272	254
			7	148	374	392	386
			8	129	316	316	328
			9	98	190	222	224
			10	82	162	152	184
			11	71	172	176	174
			12	82	152	186	152
		tmax					
			1	110	120	129	131
			2	128	140	147	154
			3	173	184	194	195
			4	228	239	247	251
			5	269	273	290	295
			6	300	313	318	329
			7	315	313	322	330
			8	310	318	329	331
			9	280	297	300	310
			10	228	246	255	256
			11	176	189	200	203
			12	124	138	139	141
		tmean					
			1	50	61	68	70
			2	64	77	85	88
			3	106	120	129	131
			4	158	173	183	186
			5	203	212	228	233
			6	240	254	260	270
			7	258	265	274	281
			8	254	267	278	281
			9	221	237	245	253
			10	160	181	190	193
			11	108	123	134	138
			12	62	77	78	80
		tmin					
			1	-10	1	6	9
			2	1	13	22	21
			3	40	55	64	66
			4	89	106	119	121
			5	138	150	165	171
			6	180	194	202	210
			7	202	217	225	231

Fort Bragg Centroid				Year			
Model	Scenario	Theme	Month	1990	2010–2039	2040–2069	2070–2099
			8	198	215	227	231
			9	162	176	189	195
			10	93	115	124	129
			11	41	57	67	72
			12	0	15	16	19
	A2						
		bio					
			1	157	170	181	193
			2	126	123	122	122
			3	38	38	38	37
			4	7464	7538	7660	7809
			5	315	320	328	342
			6	-10	2	7	15
			7	325	318	321	327
			8	250	263	273	287
			9	110	124	138	148
			10	250	263	273	287
			11	58	68	77	86
			12	1194	1298	1321	1362
			13	148	173	174	191
			14	71	71	77	76
			15	21	29	28	30
			16	394	462	462	481
			17	235	232	237	233
			18	394	462	462	481
			19	272	288	282	290
			cons_mths	272	288	282	290
		prec					
			1	91	200	186	212
			2	99	212	224	208
			3	104	220	204	206
			4	80	142	166	174
			5	93	236	246	252
			6	117	256	244	252
			7	148	322	348	382
			8	129	346	332	328
			9	98	198	218	244
			10	82	146	162	154
			11	71	154	158	152
			12	82	164	154	160
		tmax					
			1	110	123	128	135
			2	128	142	141	158
			3	173	181	194	209

Fort Bragg Centroid		Theme	Month	Year			
Model	Scenario			1990	2010–2039	2040–2069	2070–2099
			4	228	246	250	260
			5	269	281	292	308
			6	300	315	327	342
			7	315	320	328	340
			8	310	316	327	342
			9	280	288	304	316
			10	228	247	258	272
			11	176	192	201	216
			12	124	129	146	151
		tmean					
			1	50	63	68	75
			2	64	77	78	94
			3	106	115	128	142
			4	158	176	184	193
			5	203	219	230	244
			6	240	255	267	282
			7	258	267	277	290
			8	254	268	277	291
			9	221	230	248	261
			10	160	181	194	205
			11	108	127	135	149
			12	62	66	85	90
		tmin					
			1	-10	2	7	15
			2	1	12	14	29
			3	40	48	61	75
			4	89	105	117	125
			5	138	156	167	180
			6	180	194	207	221
			7	202	214	226	240
			8	198	219	227	240
			9	162	172	191	206
			10	93	114	129	138
			11	41	61	68	82
			12	0	3	23	29
	B1						
		bio					
			1	157	172	176	175
			2	126	288	291	288
			3	38	57	58	58
			4	7464	8273	8114	8096
			5	315	412	416	411
			6	-10	-92	-85	-81
			7	325	504	501	492

Fort Bragg Centroid		Theme	Month	Year			
Model	Scenario			1990	2010–2039	2040–2069	2070–2099
			8	250	279	283	280
			9	110	122	123	124
			10	250	279	283	280
			11	58	65	72	72
			12	1194	1289	1336	1344
			13	148	171	174	177
			14	71	68	80	78
			15	21	28	25	26
			16	394	462	464	469
			17	235	228	250	239
			18	394	462	464	469
			19	272	260	304	298
			cons_mths	272	260	304	298
		prec					
			1	91	188	208	212
			2	99	196	224	220
			3	104	210	222	196
			4	80	168	192	202
			5	93	218	206	246
			6	117	270	272	268
			7	148	342	348	354
			8	129	312	308	316
			9	98	218	192	196
			10	82	152	160	156
			11	71	168	164	158
			12	82	136	176	164
		tmax					
			1	110	211	214	210
			2	128	220	225	225
			3	173	270	275	278
			4	228	321	320	321
			5	269	358	378	367
			6	300	396	407	400
			7	315	412	416	411
			8	310	402	399	402
			9	280	375	380	379
			10	228	333	332	331
			11	176	272	283	274
			12	124	220	223	224
		tmean					
			1	50	60	65	65
			2	64	64	80	76
			3	106	115	119	118
			4	158	161	163	160

Fort Bragg Centroid				Year			
Model	Scenario	Theme	Month	1990	2010–2039	2040–2069	2070–2099
			5	203	217	222	222
			6	240	261	271	264
			7	258	288	294	291
			8	254	289	284	287
			9	221	240	240	243
			10	160	177	172	175
			11	108	119	127	121
			12	62	72	72	77
		tmin					
			1	-10	-91	-85	-81
			2	1	-92	-65	-74
			3	40	-41	-38	-43
			4	89	0	6	-1
			5	138	75	65	77
			6	180	125	134	127
			7	202	163	172	171
			8	198	175	169	172
			9	162	105	100	107
			10	93	21	12	19
			11	41	-34	-29	-32
			12	0	-76	-79	-70
ukmo_hadcm3							
	A1B						
		bio					
			1	157	178	190	202
			2	126	132	130	130
			3	38	41	38	37
			4	7464	7208	7582	7813
			5	315	337	354	368
			6	-10	20	15	21
			7	325	317	339	347
			8	250	268	284	301
			9	110	128	139	111
			10	250	268	284	301
			11	58	85	89	99
			12	1194	1273	1358	1516
			13	148	154	153	209
			14	71	78	78	69
			15	21	21	20	28
			16	394	416	408	503
			17	235	262	270	277
			18	394	416	408	503
			19	272	300	315	342
			cons_mths	272	300	315	342

Fort Bragg Centroid				Year			
Model	Scenario	Theme	Month	1990	2010–2039	2040–2069	2070–2099
		prec					
			1	91	216	162	196
			2	99	198	250	268
			3	104	234	264	322
			4	80	156	220	222
			5	93	182	234	232
			6	117	264	234	258
			7	148	308	306	418
			8	129	260	276	330
			9	98	204	230	222
			10	82	168	156	206
			11	71	170	166	138
			12	82	186	218	220
		tmax					
			1	110	147	138	145
			2	128	150	165	177
			3	173	200	213	221
			4	228	248	258	270
			5	269	293	305	318
			6	300	320	332	358
			7	315	337	354	368
			8	310	336	349	365
			9	280	307	318	325
			10	228	246	258	274
			11	176	193	208	218
			12	124	149	155	167
		tmean					
			1	50	86	77	83
			2	64	85	100	112
			3	106	132	145	154
			4	158	177	186	201
			5	203	224	237	250
			6	240	255	268	294
			7	258	276	295	307
			8	254	275	291	304
			9	221	245	256	264
			10	160	177	188	208
			11	108	124	139	149
			12	62	85	92	103
		tmin					
			1	-10	24	15	21
			2	1	20	35	47
			3	40	63	77	87
			4	89	105	114	131

Fort Bragg Centroid		Theme	Month	Year			
Model	Scenario			1990	2010–2039	2040–2069	2070–2099
			5	138	154	168	182
			6	180	189	204	229
			7	202	215	235	246
			8	198	214	233	242
			9	162	182	194	203
			10	93	108	117	142
			11	41	54	69	80
			12	0	20	28	39
	A2						
		bio					
			1	157	174	187	206
			2	126	136	131	137
			3	38	40	39	38
			4	7464	7489	7812	8065
			5	315	340	353	384
			6	-10	1	19	28
			7	325	339	334	356
			8	250	266	282	310
			9	110	125	137	152
			10	250	266	286	310
			11	58	74	86	100
			12	1194	1277	1359	1436
			13	148	145	175	174
			14	71	58	76	81
			15	21	21	22	24
			16	394	400	434	459
			17	235	241	285	265
			18	394	400	408	459
			19	272	284	330	312
			cons_mths	272	284	330	312
		prec					
			1	91	178	192	196
			2	99	202	224	230
			3	104	254	254	322
			4	80	212	192	236
			5	93	222	222	220
			6	117	238	196	256
			7	148	290	350	348
			8	129	272	270	314
			9	98	204	248	220
			10	82	178	174	162
			11	71	116	152	170
			12	82	188	244	198
		tmax					

Fort Bragg Centroid				Year			
Model	Scenario	Theme	Month	1990	2010–2039	2040–2069	2070–2099
			1	110	128	142	155
			2	128	146	150	178
			3	173	194	203	229
			4	228	254	253	282
			5	269	291	298	325
			6	300	315	335	364
			7	315	340	353	384
			8	310	337	353	376
			9	280	304	321	332
			10	228	247	258	279
			11	176	194	199	223
			12	124	144	156	166
		tmean					
			1	50	65	81	92
			2	64	80	85	110
			3	106	124	135	157
			4	158	181	182	208
			5	203	220	230	254
			6	240	248	271	298
			7	258	276	293	320
			8	254	274	294	312
			9	221	239	259	268
			10	160	176	189	208
			11	108	123	130	150
			12	62	78	93	99
		tmin					
			1	-10	1	19	28
			2	1	13	19	41
			3	40	53	67	85
			4	89	107	111	133
			5	138	149	161	182
			6	180	180	206	231
			7	202	211	232	256
			8	198	211	235	248
			9	162	173	197	203
			10	93	105	119	137
			11	41	52	60	76
			12	0	11	29	32
	B1						
		bio					
			1	157	172	181	191
			2	126	148	140	144
			3	38	41	41	41
			4	7464	7573	7636	7360

Fort Bragg Centroid				Year			
Model	Scenario	Theme	Month	1990	2010–2039	2040–2069	2070–2099
			5	315	345	347	362
			6	-10	-8	6	12
			7	325	353	341	350
			8	250	262	277	284
			9	110	85	131	147
			10	250	269	277	284
			11	58	74	80	95
			12	1194	1244	1352	1379
			13	148	161	173	169
			14	71	66	69	77
			15	21	23	24	22
			16	394	408	436	447
			17	235	245	256	259
			18	394	397	436	447
			19	272	283	302	318
			cons_mths	272	283	302	318
		prec					
			1	91	168	174	210
			2	99	208	222	224
			3	104	214	256	262
			4	80	160	254	210
			5	93	194	186	192
			6	117	208	246	262
			7	148	322	346	338
			8	129	264	280	294
			9	98	230	228	248
			10	82	198	166	162
			11	71	132	138	154
			12	82	190	208	202
		tmax					
			1	110	134	141	151
			2	128	156	152	168
			3	173	200	209	217
			4	228	249	264	265
			5	269	289	298	308
			6	300	328	333	341
			7	315	341	347	362
			8	310	345	344	350
			9	280	307	312	322
			10	228	254	256	265
			11	176	196	200	219
			12	124	150	157	179
		tmean					
			1	50	63	74	82

Fort Bragg Centroid		Theme	Month	Year			
Model	Scenario			1990	2010–2039	2040–2069	2070–2099
			2	64	82	81	96
			3	106	122	135	141
			4	158	168	187	186
			5	203	213	225	234
			6	240	256	266	271
			7	258	274	284	296
			8	254	277	283	285
			9	221	236	246	255
			10	160	176	181	191
			11	108	117	125	143
			12	62	77	87	107
		tmin					
			1	-10	-8	6	12
			2	1	7	9	23
			3	40	44	60	65
			4	89	86	110	107
			5	138	137	152	159
			6	180	184	198	201
			7	202	206	220	230
			8	198	209	221	219
			9	162	165	180	187
			10	93	97	105	116
			11	41	38	50	66
			12	0	3	17	35

Appendix C: Dataset Generation Processes

To ensure that they had complete understanding of the methodology CIAT used to generate their data, researchers reviewed the available on line literature and summarized the processing as follows.

C.1 WorldClim

The WorldClim database was created as a result of a 2005 study published in the International Journal of Climatology (Hijmans et al. 2005). Monthly averages of climate at weather stations were compiled for a period of approximately 1950-2000 and interpolated using a thin-plate smoothing spline algorithm. The process resulted in 1 km resolution global climate surfaces (land areas only – excluding Antarctica) for monthly precipitation and minimum, mean, and maximum temperature.

Weather station data were collected from multiple sources:

- Global Historical Climate Network Dataset (GHCN)
- WMO climatological normals (CLINO)
- FAOCLIM 2.0 global climate database
- International Center for Tropical Agriculture (CIAT) database assembled by Peter G. Jones and collaborators
- Additional regional databases for Latin America, the Altiplano in Peru and Bolivia, and the “Nordic Countries” in Europe, Australia, New Zealand, and Madagascar.

As a measure of quality control, Hijmans et al. used ANUSPLIN-SPLINA 4.3 to implement a thin-spline smoothing procedure. They then used manual verification of spatial and elevation data for weather station points in conjunction with SPLINA to identify the stations displaying data with the largest difference between the “real” data and that in the spline fitted climate surface. Data records thus identified with errors were either corrected or removed.

The construction of the global climate surfaces used elevation data from both the Shuttle Radar Topography Mission (SRTM) and the GTOPO30 database. Monthly surfaces for precipitation and minimum, maximum, and mean temperature were created while uncertainty in the interpolation process was dealt with through two strategies. First, the authors calculated elevation bias in weather stations as the difference between the mean elevation of a GCM scale grid cell and the mean elevation of the weather stations therein. Second, they used SPLINA to build a surface based on only half of the stations, then mapped the differences between the other observed half and the predicted values to illuminate any inconsistencies.

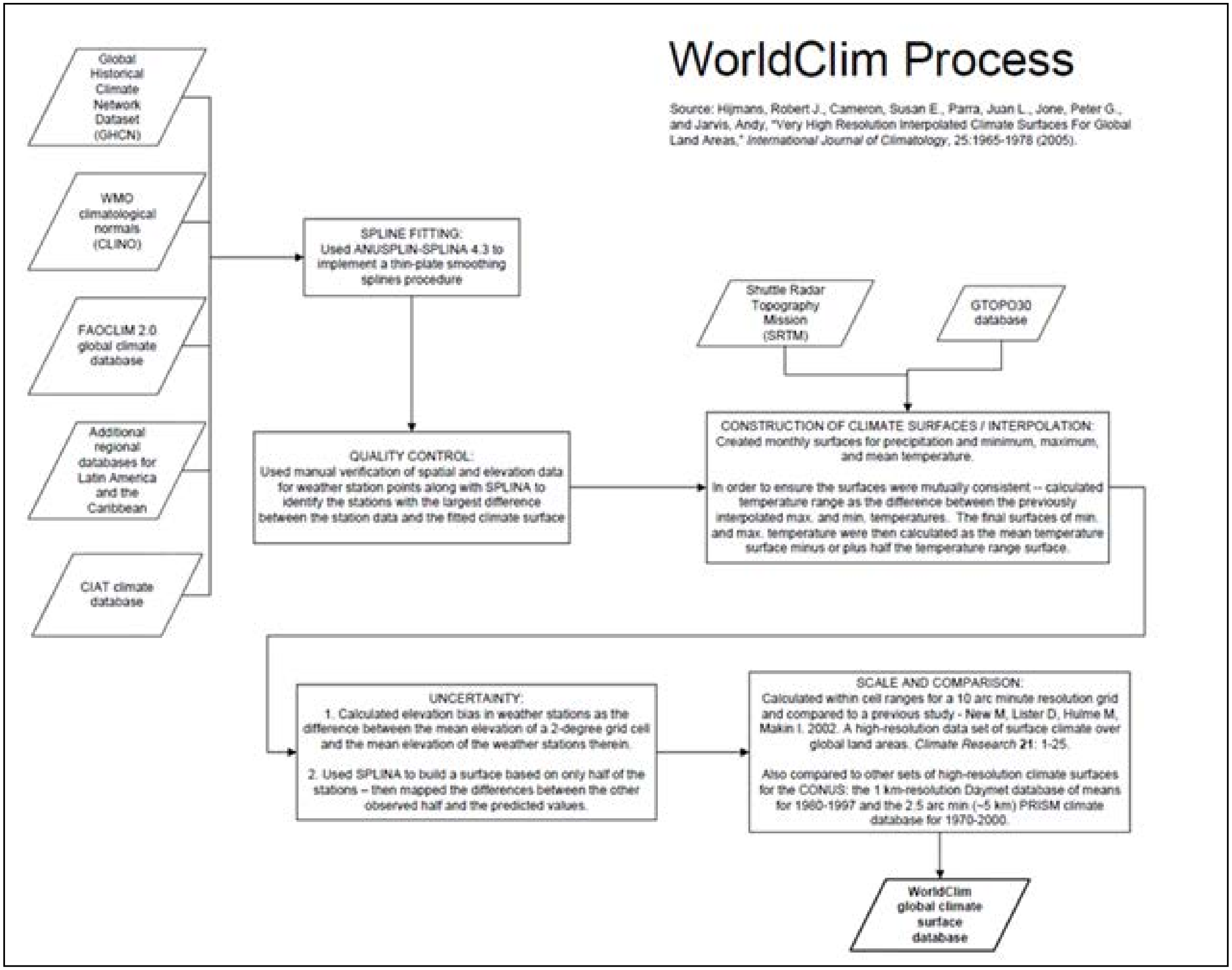
To illustrate the importance of high-resolution datasets, the authors calculated “within cell ranges” for a 10 arc-minute resolution grid based on their 1-km resolution surface (10 arc-minutes was previously the highest resolution global climate dataset available (New et al. 2002). The calculated ranges of annual mean temperature and annual precipitation were compared to New et al. (2002) and two other sets of high-resolution climate surfaces with a spatial coverage of only the CONUS: the 1-km resolution Daymet database of means for 1980-1997 and the 2.5 arc-minute (~5km) PRISM climate database for 1970-2000.

Figure C1 shows the WorldClim data processing flow chart.

C.2 International Centre for Tropical Agriculture (CIAT)

The CIAT spatially downscaled data (Delta Method) (CCAFS 2011b) is based on the sum of interpolated anomalies to the high-resolution monthly climate surfaces from WorldClim (Ramirez and Jarvis 2010). The dataset features smoothed (interpolated) global surfaces of multiple (19-24 depending on scenario) GCMs from the IPCC Fourth Assessment Report. It includes GCM output from three emissions scenarios (SRES-A1B, SRES-A2, and SRES-B1) for several 30-year running mean periods (2010-2039 [2025s], 2030-2059 [2045s], 2040-2069 [2055s], 2050-2079 [2065s], 2060-2089 [2075s], and 2070-2099 [2085s]).

Figure C1. WorldClim data processing flow chart.



Each dataset (comprised of an SRES scenario, a GCM and a timeframe) includes four separate monthly variables: mean, maximum, and minimum temperature. and total precipitation. Each dataset is also available at four spatial resolutions 30 arc-seconds (~1 km), 2.5 arc-minutes (4.5 km), 5 arc-minutes (9.25 km) and 10 arc-minutes (18.5 km) (1 minute = 1.85 km, per Penna 2002).

The Delta downscaling method makes the following gross assumptions:

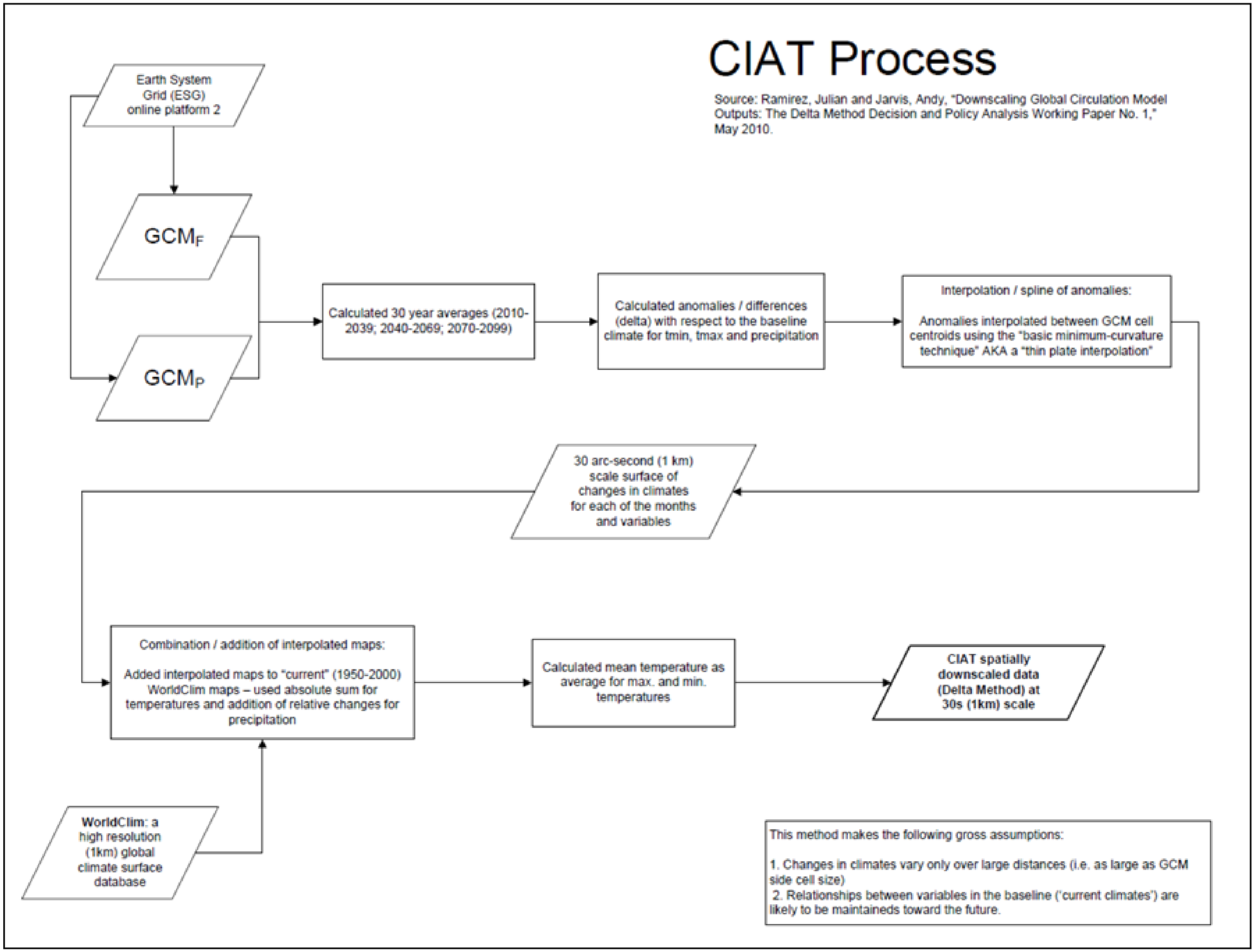
- Changes in climates vary only over large distances (i.e., as large as the original cell size).
- Relationships between variables in the baseline ("current climates") are likely to be maintained towards the future.

Initial data were compiled from the Earth System Grid (ESG) online platform and included monthly records and projections from 1850-2100. Future projections were then grouped into 30-year averages before anomalies (delta or differences) were calculated between the gathered baseline climate observations and future projections for minimum/maximum temperature and precipitation. After a further manipulation involving a "thin-plate interpolation" in which the anomalies were interpolated between GCM cell centroids, CIAT was left with a 30 arc-second (1 km) scale surface of changes in climates for each month and variable in the dataset.

The final interpolation involved combining CIAT's downscaled data with that from WorldClim. Interpolated maps were added to the "current" WorldClim maps (1950-2000) account for the possible bias due to the difference between WorldClim's downscaled baseline data and the lower resolution observations obtained through ESG. Finally, mean temperature was calculated as the average between minimum and maximum temperature variables.

Figure C2 shows the CIAT data processing flow chart.

Figure C2. CIAT data processing flow chart.



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14. ABSTRACT

The effects of climate change are expected to impact military installations in the Continental United States (CONUS), including Army installations that have large land-based range areas used for testing, training, or maneuvers. Climate change has the potential to affect several management concerns at Army installations. Natural areas may shift on installations and change the costs to maintain training and testing areas. Climate change is likely to increase the management costs for Threatened and Endangered Species (TES) and noxious invasive species (NIS). This document describes a set of climate change data gathered to support a larger project undertaken to determine the thresholds of climatic characteristics of these targeted species. This work describes available climatic data that will show what the major Global Climatic Models (GCMs) predict about those changes, using Fort Bragg, NC as an example.

15. SUBJECT TERMS
climate change, Ft. Bragg, NC, natural resource management, modeling, land use planning

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